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COMPUTERIZED SURVIVOR SEARCH PLANNING

by

Joseph Henry Discenza

United States Naval Postgraduate School



THESIS

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June 1969

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Computerized Survivor Search Planning

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
June 1969

NPS ARCHIVE
1969
DISCENZA, J.

~~48-5578~~

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ABSTRACT

A computer program is presented which solves the search planning problem for survivors at sea. The program is designed to utilize weather data as compiled by the United States Navy at its Fleet Numerical Weather Central, Monterey, California.

An investigation is also made into the search criteria used by the United States Coast Guard in its planning procedures. Guidelines are given for the use of the square search and the Sector search.

TABLE OF CONTENTS

I. INTRODUCTION-----	5
A. THE COAST GUARD AND SURVIVOR SEARCH--	5
B. DOCTRINE-----	6
C. PURPOSE-----	7
II. THE SEARCH PLANNING PROGRAM-----	8
A. OBJECTIVE-----	8
B. THE MANUAL METHOD-----	8
C. THE COMPUTER PROGRAM-----	12
D. CALCULATING DRIFT WITH THE COMPUTER--	16
E. VERSIONS OF THE PROGRAM-----	23
SAMPLE COMPUTER OUTPUT-----	25
III. SEARCH THEORY-----	28
A. DETECTION LAWS-----	29
B. DISTRIBUTION OF SEARCH EFFORT-----	35
IV. THE UNIFORM COVERAGE SQUARE SEARCH-----	38
A. THE PROBLEM-----	38
B. TERMS-----	39
C. THE SOLUTION-----	40
D. THE GENERAL CASE-----	54
V. THE SECTOR SEARCH-----	59
A. SEARCH EFFORT DISTRIBUTION-----	59
B. PATTERN ERROR-----	61
C. OPTIMUM SECTOR SEARCH-----	64

VI. CONCLUSIONS AND RECOMMENDATIONS-----	71
A. THE SEARCH PLANNING PROGRAM-----	71
B. DETERMINATION OF SEARCH AREAS-----	74
C. FUTURE RESEARCH-----	74
D. CONCLUSION-----	78
APPENDIX A - USER'S GUIDE TO SEARCH PLANNING	
PROGRAM-----	79
COMPUTER OUTPUT - OPTIMUM SQUARE SEARCH-----	85
COMPUTER PROGRAM - SEARCH PLANNING PROGRAM---	86
COMPUTER PROGRAM - OPTIMUM SQUARE SEARCH-----	107
REFERENCES-----	114
INITIAL DISTRIBUTION LIST-----	115
FORM DD 1473-----	117

I. INTRODUCTION

A. THE COAST GUARD AND SURVIVOR SEARCH

Survivor search is defined as the process of planning and executing a search for survivors at sea, and the Coast Guard usually accomplishes this in the following steps:

1. Initial Notification

This stage involves gathering all available data about persons or craft in distress, including characteristics of the survivor craft, number of survivors, etc.

2. Initial Distress Position

In this stage, the search planner puts together all the available data concerning the survivor and makes a judgement as to what the most likely position of the survivor was at the time the craft ceased operating normally.

3. Drift Calculations

The survivor's suspected motion is plotted assuming drift in the open ocean, and a position is calculated for some future time, usually the planned beginning of search efforts.

4. Calculation of the Area to be Searched

An estimate is made of the accuracy of the survivor's position as calculated in step 3 and the accuracy of navigation of the search craft. An area, called the

Search Area, is defined based on these errors.

5. Allocation of Search Units

A determination is made of the resources (ships, planes, boats, etc.) to be used in the search, and the way in which these resources will be used.

6. Execution of the Search

Searching is accomplished according to several established search patterns, most of which are different arrangements of a series of parallel paths within the Search Area.

7. Termination of the Search

Either the survivors are located or, after a certain amount of searching is completed without success, the search is terminated. This stage includes reports, and the evaluation of search effort.

B. DOCTRINE

The guidance for all these activities is contained in Coast Guard publication CG-308, the National Search and Rescue Manual, (Ref. 1.). Chapters 3 through 8 of this manual contain the instructions for planning and conducting a search for survivors at sea.

C. PURPOSE

This thesis accomplishes two things:

1. Provides a computerized solution to step 3 of the search planning process, calculating survivor craft drift, and
2. Investigates the criteria used for allocation of resources to a search, steps 4, 5, and 6.

It is intended that the results be understood by the search planner, so that they may be of some use to him.

II. THE SEARCH PLANNING PROGRAM

A. OBJECTIVE

The major objective in designing a computer program for search planning was to have a fast, accurate means of obtaining an estimate of a survivor's oceanic position at the time of the beginning of a search.

B. THE MANUAL METHOD

In order to understand the program, it is first necessary to understand how drift plotting is done manually.

1. Example

A fishing vessel is believed to have sunk at latitude 40-42.0N, and longitude 52-13.0W, at 0900z on 22 June. The probable error of this position is estimated to be 30 miles. Although the standard measure of variability is the standard deviation, all error estimates made in the search planning process are in terms of probable error. It will be demonstrated that this error is defined by the statistical term, "probable error". Survivors are believed to be in rubber rafts.

The proper Coast Guard authorities are notified at

2100Z on 22 June, and a search plane has been dispatched. It is due to arrive on the scene at 0100Z 23 June. The aircraft's navigation error (again a probable error) is estimated to be 10 miles.

2. Gathering Data

The first task of the search planner is to estimate wind, wind current, and sea current at the position of the sinking. Wind is obtained from observations, weather maps, Navy Fleet weather services, or the U.S. Weather Bureau, whichever is available. Wind current is computed from the wind by means of a graph given in the National Search and Rescue Manual. Average Sea Current is obtained from ocean current charts or pilot charts. These sources for average sea current are compiled from observations made over several years. (Thus this data may not be accurate for the time and place of concern, but so far they have been the only data available to the search planner.)

3. Drift Plotting

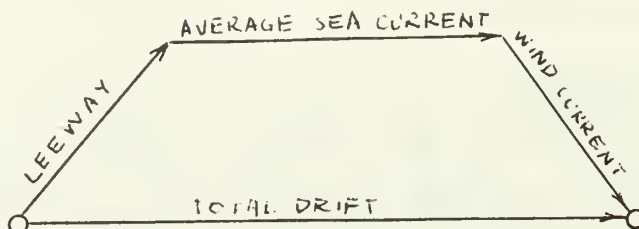
a. Leeway

Leeway is the motion of the survivor craft caused by wind. For the example case of a liferaft, two graphs are provided in the SAR Manual for computing leeway. One graph is for when a drogue is attached to the raft (a drogue is a type of sea anchor designed to retard liferaft leeway) and the other is for when a drogue is not attached. If it is not known whether a drogue is attached, both conditions are

considered separately.

b. Total Drift

Once leeway, wind current, and average sea current have been determined, they are added vectorially to produce total liferaft drift.



This calculation can be done for intervals of any length - one hour, three hours, twelve hours - but the interval most commonly used is the interval between wind observations. That is if wind is available for 0900Z, 1200Z, 1500Z, etc., the search planner would probably compute total drift in three hour intervals, from 0900Z on the 22nd to 0100Z on the 23rd. Each time total drift is calculated (another probable error), 12.5% of that distance is retained as "drift error", and the drift errors are summed to obtain total drift error.

Example: In this manner, the position of the example liferaft is calculated to be 40-58.0N, 51-55.0W, and the drift error is 4.0 miles.

c. Minimax Plotting

If it is unknown whether a drogue was in use, two plots are made, and the final ("datum") position is defined to be midway between the two positions calculated.

The drift error is a function of the two calculated drift errors and the distance between the two positions. This process of plotting two positions is called Minimax plotting in the SAR Manual.

d. Error of Position

Once the datum has been computed, it is then necessary to find total probable error of position, c , where

de = total drift error

X = error in initial position of survivor craft

Y = navigation error of search craft

$$c = \sqrt{de^2 + X^2 + Y^2}$$

For the example, $c = \sqrt{16+100+900} = \sqrt{1016} = 31.9$ miles.

e. Safety Factor

To determine the size of the area to be searched, a search "radius", R is found by multiplying c by a safety factor, depending on which search in a sequence is being planned. For searches one through five, the respective safety factors are 1.1, 1.6, 2.0, 2.3, and 2.5. The example of the sunken fishing boat is a first search, so $R = 1.1 \times 14.7 = 16.2$ miles.

The area to be searched, then, is a square with sides = $2 \times R$, centered on datum:



f. Sweep Width

The standard measure of the effective search width of a search craft is called "sweep width". The value of the sweep width is obtained from a table in the Search and Rescue Manual, based on the type of target, search altitude, and meteorological visibility. The sweep width thus obtained is corrected for the effect of sea state by multiplying by a "whitecap correction factor" which is tabulated for various wind speeds.

C. THE COMPUTER PROGRAM

1. Objective

The computer program accomplishes the objective of providing an estimate of the survivor's position by automating the steps of the manual method of drift plotting.

2. Source of Weather Data

In choosing a source of weather data for the computer program, three criteria were considered: a. availability, b. computer access time, and c. accuracy. The final selection for data source was the Navy Fleet Numerical Weather Central, Monterey.

a. Availability

FNWC Weather data is compiled twice daily, at

0000Z and 1200Z, and is directly available, either by data link or, for testing purposes, on magnetic tape. For use with this program, the data is stacked chronologically on a master tape.

b. Computer Access Time

With the exception of the mounting of the master weather tape, all weather data handling is eliminated. Access speed, then, is limited only by the speed of the tape transport.

c. Accuracy

Although the data used is intended for wide area coverage, its probable error is less than the probable error assumed when computing drift error (12.5%). Although there will be occasions when local weather reports are available and may be more accurate, the bulk of search planning is done under conditions of incomplete weather analysis and forecasts, and when gross estimates must be made. Since the weather analyses for a particular time period and geographical location, once assembled for this program, are fixed parameters, repeated computations of the same search problem will always produce identical answers. This permits a rigorous evaluation of the data, methods, and assumptions used in search planning by a systematic testing procedure.

3. Data Description

The weather data are produced by FNWC for 3,969 geographical points in the northern hemisphere. These data

points are intersections of a 63 X 63 square grid superimposed on a polar stereographic map projection. Grid point (32,32) is at the north pole, and the vertical line ($i=32$) is coincidental with the 80 W and 100 E meridians. A sample projection is shown as Figure 1.

The polar stereographic projection provides a plotting reference which shows an entire hemisphere with the least possible distortion (Ref. 6), and the scale is true at 60 degrees North Latitude. Conversion from latitude (L) and longitude (λ) to grid coordinates is accomplished by the following formulas:

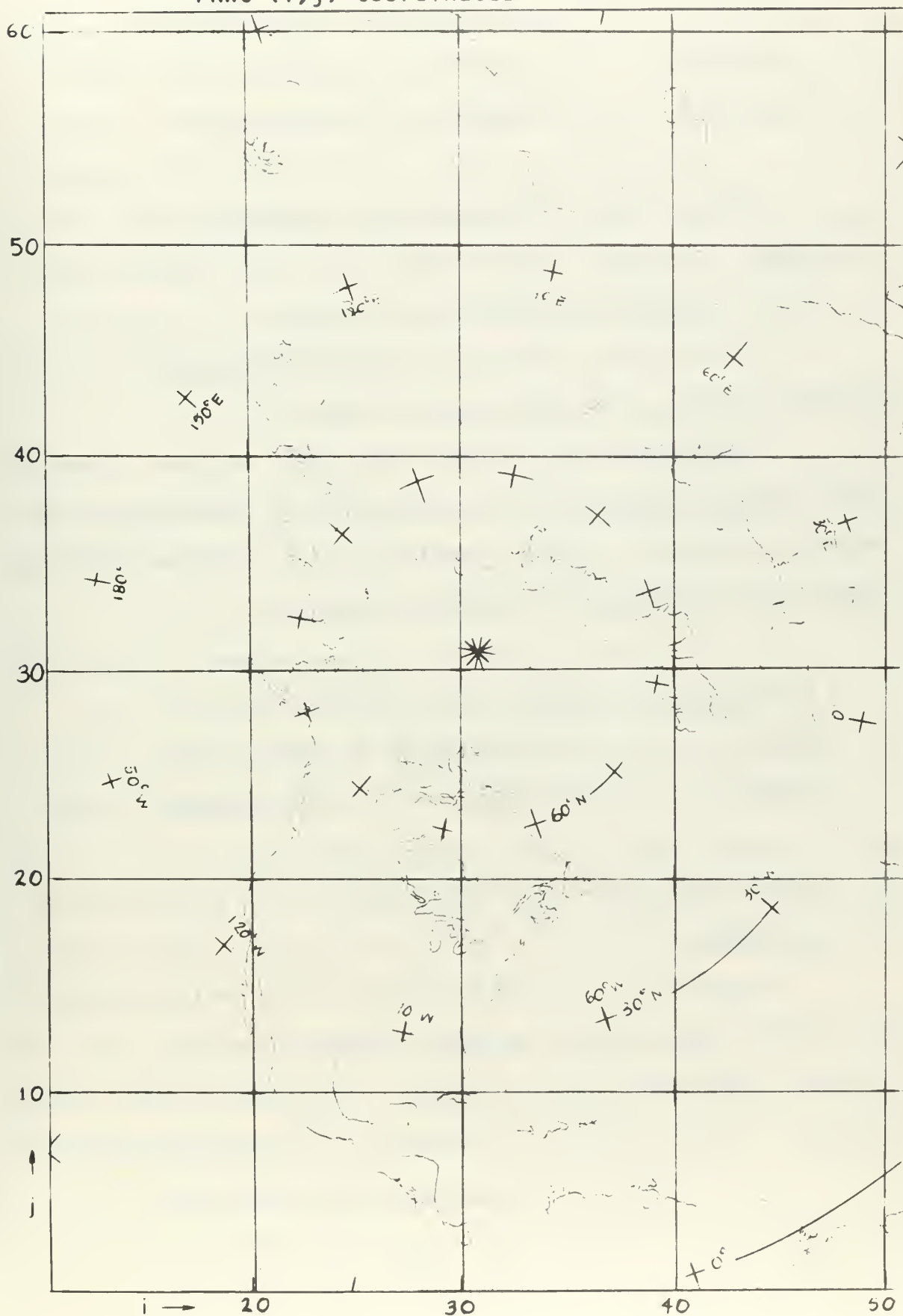
$$i = 32 + 31.205 \left(\frac{1 - \sin L}{1 + \sin L} \right)^{\frac{1}{2}} \cos(\lambda + 10^\circ) \quad (1)$$

$$j = 32 - 31.205 \left(\frac{1 - \sin L}{1 + \sin L} \right)^{\frac{1}{2}} \sin(\lambda + 10^\circ) \quad (2)$$

For the example, $i = 38.008$, and $j = 19.0143$.

The data is stored in "fields" of 3,969 words (numbers), each word being some component of atmospheric or oceanic conditions at its corresponding (i,j) grid position. The fields required for direct input to this program are:

Figure 1. Portion of Polar Stereographic Projection Showing FNWC (i,j) Coordinates



U Curr	U- component of surface current
V Curr	V- component of surface current
U Marine	U- component of surface wind
V Marine	V- component of surface wind

where the U direction is parallel to the "i" or horizontal axis and the V direction is parallel to the "j" or vertical axis, in the FNWC grid system.

The Current information as provided by FNWC is total surface current, including wind current.

Fleet Numerical did not regularly produce U Marine and V Marine wind fields, so these fields are computed by a separate computer program provided by the Weather Facility using the following data fields as input:

D 1000	Height of the 1000-mb pressure line
T Air	Air temperature at the surface
T Sea	Sea temperature at the surface

D. CALCULATING DRIFT WITH THE COMPUTER

1. Leeway

In addition to the liferaft drift tables given in the Search and Rescue manual, there are other ways to predict the leeway of a survivor craft. Most of these methods involve using a percent of the wind speed to

determine the leeway speed, and some deflection in degrees to determine the direction of leeway off the wind line. For example, a boat type may be known to drift in a direction 40 degrees off the wind line, and at a speed equal to 4% of the wind. To accomodate these methods as well as the liferaft drift table from the SAR Manual, several options are available to the user of this computer program.

2. Options for Leeway

a. A function approximating the liferaft drift tables in the National SAR Manual has been provided; drifting speeds for with drogue and without drogue are both available.

b. Leeway speed can also be specified as a percent of wind, in whole numbers, from 2% to 9%.

c. For each of the leeway velocities in b., a deflection off the wind line of plus or minus some angle, in tens of degrees, from 0 to 90 degrees, may be specified.

d. A minimum-maximum leeway speed option with the minimum being 1% of the wind, and the maximum being some whole number percent from 2% to 9% of wind speed, is available.

e. No leeway at all (as in the case of a man in the water or some other almost completely submerged object) may be specified.

3. Adjustment of Input Data

a. Dates

All dates are converted from month and day to julian dates, to permit reference to weather data and adjustment of the program "clock".

b. Latitude and Longitude

All initial positions are converted to FNWC (i,j) coordinates.

c. Leeway Options

Leeway options are entered by means of a two-digit code, which is converted to speed and direction of drift within the program.

d. Weather

Wind and current are provided in units of cm./sec. and are scaled in the program to nautical miles per hour. They are further scaled to decimal fractions of the FNWC grid distance.

4. Interpolation of Weather Data

a. Interpolation for Position

For each position in (i,j) coordinates there are four neighboring grid intersections for which weather is tabulated. Example:

GRID POSITION: i=38.00787

j=19.01413

GRID POINTS: . (38,20) . (39,20)

. (38,19) . (39,19)

All weather data are interpolated linearly among

these four neighboring points. For example, if U Current at 0000Z at grid points (i,j) is:

$$(38,20) = 50.0 \quad (39,20) = 49.0$$

$$(38,19) = 42.0 \quad (39,19) = 40.0$$

then for $i=38$, $j=19.01413$,

$$U \text{ Current} = 42.0 + .01413 \times (50-42) = 42.112$$

and for $i=39$, a similar computation results in U Current = 40.12717.

U Current for the position is then,

$$42.112 + .00787 \times (-1.985) = 42.097 \text{ cm./sec.}$$

b. Interpolation for Time

For each hour in the computation, there are two observation times which are used to supply weather data: 0000Z and 1200Z, one of which will be prior to the hour, and one which will be after the hour. A linear interpolation for position is done for each observation, and then these two values are interpolated linearly for time. For example, if the U Curr for 1200Z is calculated as above and found to be 37.25 cm./sec., the interpolation for time is accomplished as follows:

$$46.09 + 9/12 \times (-8.84) = 39.46 \text{ cm./sec.}$$

c. The Clock

A complete set of interpolations is done for each position and for each weather parameter at the start of the drift calculations, and each position is advanced for an hour's worth of drift. This interval is used as a

compromise between accuracy requirements and computer time. If an interval much smaller than one hour were used, a large increase in computer time would be required. A problem which would take 20 seconds at one hour intervals would cost almost 20 minutes of computer time if one minute intervals were used.

After the one hour's worth of drift is computed, and the positions updated, the clock is advanced one hour, and the process is repeated over and over until the end of the problem.

5. Drift Plotting

Drift calculations are applied to the (i,j) coordinates of the survivor craft plot. That is, the U-component of drift is added to the "i" coordinate of the survivor position and the V-component is added to the "j" coordinate.

Example: The interpolated values of current and wind for 0900Z on 22 June are

Parameter	cm./sec.	miles/hour
U Curr	+ 39.460	+ .766
V Curr	+ 36.128	+ .702
U Marine	+250.78	+ 4.87
V Marine	-850.25	-16.55

the wind speed then equals $\sqrt{4.87^2 + 16.55^2} = 17.25$ nautical miles/hour. For a liferaft without drogue, this wind speed produces a leeway of 0.94 miles per hour as

follows:

$$\text{Leeway} = .226 \times \sqrt{17.25} = 0.94$$

This formula is an approximation to the liferaft drift table given in the Search and Rescue Manual.

Since $\arctan (4.87/-16.55)$ equals 163.6 degrees, this angle is a measure of the wind angle (measured clockwise from the vertical (in the FNWC system):



If leeway deflection is specified by the user, it is applied to this wind angle, before the U and V components of leeway are calculated. The reduction of Leeway and wind angle to U and V components is as follows:

$$U \text{ Leeway} = 0.94 \times \sin(163.6^{\circ}) = 0.266$$

$$V \text{ Leeway} = 0.94 \times \cos(163.6^{\circ}) = -0.902$$

The leeway and current are applied to the position

as follows:

	U	V
Leeway	.266	-.902
Current	<u>.766</u>	<u>.702</u>
Total	1.032	-.200 knots

These values are then divided by the distance between gridpoints, at this latitude = 235.37 miles:

	.00439	-.00085
+ position	<u>38.00787</u>	<u>19.01413</u>
New Position	38.01226	19.01328 for 1000Z 22 June.

This process is repeated hour by hour until the last datum has been calculated, drift plotting ceases, and calculations for position error and Search Radius begin.

6. Position Error

Just as in the manual method, the initial position error of the survivor craft is computed as follows:

x = distance of initial (or distress) position from last known position.

A = error of last known position

B = navigation error of survivor craft as a percent of distance traveled

The initial position error, X , is

$$X = A + Bx$$

Since Y is the navigation error of the searcher, and d_e is the drift error, the Total Probable Error, c , of

Position is

$$c = \sqrt{X^2 + Y^2 + de^2}$$

7. Safety Factor

c, Total Probable Error of Position is multiplied by the safety factor to find the Search Radius as prescribed in the Search and Rescue Manual.

8. Sweep Width

A numerical approximation to the data in Richardson's Sweep Width tables (Ref. 4) may be seen to be:

$$W = -3.34377 + 1.25887 \log(l) + 2.55442 \log(V) + .01023 h$$

where l is boat length

V is visibility in miles, and

h is search altitude in thousands of feet.

In addition, corrections to Sweep Width for whitecaps based on wind speed (v) and cloud cover (C) can be approximated by:

$$F1 = .886 + .298X - .116 X^2 \text{ (whitecaps, } X = v/10)$$

$$F2 = 1.131 - .472C + .152C^2 \text{ (cloud cover)}$$

These correction factors are multiplied by W to obtain final Sweep Width. This Sweep Width function is applicable to small boats only. No Sweep Width for large ships or for liferafts is available in the program.

E. VERSIONS OF THE PROGRAM

The Search Planning Program is written in FORTRAN IV for

use on a remote computer terminal. A second version is written for use on the operations computer at Fleet Numerical Weather Facility. No remote terminal operation is available there, so these two versions are different in several ways:

1. Input-Output

a. The time sharing version is written for entry of data by the search planner onto a remote console, and the results are printed out immediately on the same console. This permits the planner to control the program during execution, and to make intermediate decisions concerning the problem. An example of the output of the time-sharing version is shown on the next two pages. Note that items typed in by the user are shown in lower case, and the replies typed on the console by the computer are in upper case. The final output includes sweep width, total probable error of position, search radius, and calculated wind.

b. The batch-processing version at FNWC differs from this in that it requires cards to be punched for input, and the output is printed in message form, ready for transmission back to the requestor.

2. Features Omitted

For the operational version of the program at Fleet Numerical Weather Facility the following items of output shown on the sample time-sharing printout were not made available:

```

$ sar
EXECUTION BEGINS...
  MONTEREY SEARCH PLANNING PROGRAM
  ENTER LEEWAY CODE, 1 BLANK, THEN DESCRIPTION
> 11 liferaft
  HOW MANY STARTING POINTS WILL BE ENTERED?
> 1
  LIST CHRONOLOGICALLY: STARTING TIMES AND POSITIONS, EX:
  070930Z MAR,3822.5N,06806.5W
> 220900z jun,4042.0n,05213.0w
    40      42.0      52      13.0    CHECK:N    W
  CHECK. TYPE Y OR N
> y
  ENTER NUMBER OF TIMES DATUM IS TO BE COMPUTED NOW:
> 2
  ENTER THESE DTGS. EX:020900 MAR,031030 MAR
> 230100 jun,230700 jun
  SEARCH 1, TRACK 1, DATUM:      40 50.21      51 51.96
  SEARCH 2, TRACK 1, DATUM:      40 53.26      51 44.04
  ENTER LAST KNOWN POSITION. EX: 3522.0N,07653.0W
> 4100.0n,05400.0w
  IS LIFERAFT
  A (1)BOAT, (2)SHIP, OR (3)AIRCRAFT?(ENTER 1,2,OR3)
> 1
  ENTER SEARCH UNIT FIX ERROR, Y. EX: 5.0
> 5.0
  INDICATED DISTRESS CRAFT POSITION ERROR,X:
  X= 15.00(1) + 0.15(2) TIMES DIST. FROM LAST KNOWN POSITION.
  ANY CORRECTIONS? (TYPE 0,1,2, OR 12)
> 1
  ENTER PARAMETER(1):
> 20.0
  IS EACH DATUM TIME A DIFFERENT SEARCH (1,2,3,ETC.)?
> no
  ENTER SEARCH NUMBER CORRESPONDING TO DATUM TIME:
  ** 1 0 SEARCH:
> 1
  ** 7 0 SEARCH:

```

> 0
 THE FOLLOWING ARE THE DATUM POINTS FOR THE
 1: 0 SEARCH:
 40-50.2N 51-52.0W POS. ERROR: 41.8, RADIUS: 46.0 MILES;
 WIND 34.4KTS FROM 267.
 SWEEP WIDTH? Y OR N
 > y
 ENTER SEARCH ALTITUDE (EX:800.)
 > 1000.
 ENTER VISIBILITY IN MILES (EX:10.0)
 > 20.0
 ENTER BOAT LENGTH IN FEET (EX:36.0)
 > 10.
 ENTER CLOUD COVER IN FRACTION (EX: 0.9)
 > 0.1
 SWEEP WIDTH= 4.6 MILES.
 THE FOLLOWING ARE THE DATUM POINTS FOR THE
 7: 0 SEARCH:
 40-53.3N 51-44.0W POS. ERROR: 41.9, RADIUS: 0.0 MILES;
 WIND 34.4KTS FROM 267.
 GOOD LUCK ON YOUR SEARCH! LET ME KNOW IF YOU FIND
 THELIFERAFT

IHC0021 STOP 0
 R; T=1.00/2.87 13.11.18

Note: Inputs marked with ">"

a. Printout of intermediate track positions (SEARCH 1, TRACK 1, etc.) is not produced.

b. On scene Wind

Since the wind printout as shown in the sample time-sharing output is only the wind velocity and direction at the beginning of the search, and may not be representative of the average weather conditions throughout the search, this value is not included.

c. Sweep Width

Since the the computation of sweep width requires data which may not be immediately available to the search planner at the time of his request, and since the formula applies only to small boats, this feature was not included in the Fleet Numerical version.

d. Leeway

For the Fleet Numerical version, leeway is calculated as described in D.2. The time sharing version uses a square root function for all leeway. If N is the percentage drift specified (1% to 9%), the leeway function in the time sharing version is

$$LEEWAY = \frac{N}{25} \sqrt{WIND} \quad (3)$$

This function produces leeway which is equal to N% of the wind for wind speeds of 16.0 knots. For other wind velocities the function follows the general contour of the liferaft leeway (without drogue) table in the Search and Rescue Manual.

III. SEARCH THEORY

In part III the method of estimating the position of the search object and the rules for determining the size of the search area were discussed. This is only part of the search planning process; this section will consider how resources are assigned to the search, and how the effectiveness of the search is measured.

In a search pattern employing parallel sweeps, the distance between these sweeps is called track spacing, S . The Search and Rescue Manual recommends that for urgent cases the track spacing used be equal to the Sweep Width, W , and for less urgent cases it be equal to twice the Sweep Width. Once the value of track spacing has been decided upon, the amount of searching required (in miles flown) L can be computed from S and the area A to be searched:

$$L = A/S$$

The measure of effectiveness of a search which is given in the Search and Rescue Manual is called Probability of Detection, and it is presented as a series of curves plotted against "coverage factor" or W/S . These curves are called

"first search", "second search", etc., probabilities. If p is the probability of detection in the first search curve, the probabilities 2,...n..5 are given by

$$p = 1 - (1 - p)^n$$

These curves do not take into account the size of the area searched, however, so that a search can be conducted in a very small area using a high coverage factor which will yield a very high probability of detection according to the graph. Common sense indicates that to confine the search to a very small area will probably not result in the detection of the target. Nowhere does the Search and Rescue Manual define the probability that the target is in the search area.

The absence of the treatment of this seemingly critical factor led the author to a review of the field of search theory as it applies to survivor search.

The basis for most of the search planning criteria in the National Search and Rescue Manual was found in Koopman's (1944) work, Search and Screening (Ref. 2). This treatise developed the concept of sweep width, and found the probability of detection for various situations.

A. DETECTION LAWS

1. Instantaneous Probability of Detection

If γ is defined so that the probability of detecting a target in a short period of time dt is γdt , then the quantity γ is called the instantaneous probability density of detection. When the searching is done during a time t under constant conditions, the probability $p(t)$ of detection is given by

$$p(t) = 1 - e^{-\gamma t} \quad (4)$$

Search and Screening developed this quantity for various situations.

a. Definite Range Law

This law assumes that there is a certain range R from the observer beyond which it is impossible to detect the target; inside this range detection is certain. Instantaneous probability of detection by this law is

$$\begin{aligned} \gamma(r) &= \infty & r \leq R \\ \gamma(r) &= 0 & r > R \end{aligned} \quad (5)$$

b. Inverse Cube Law

The inverse cube law is the result of making the following assumptions:

- (1) The observer is at an altitude h above the ocean.
- (2) The observer detects the target by seeing its wake.
- (3) The instantaneous probability of detection

is proportional to the solid angle subtended at the point of observation by the wake.

The calculation of the solid angle is shown in figure 2.

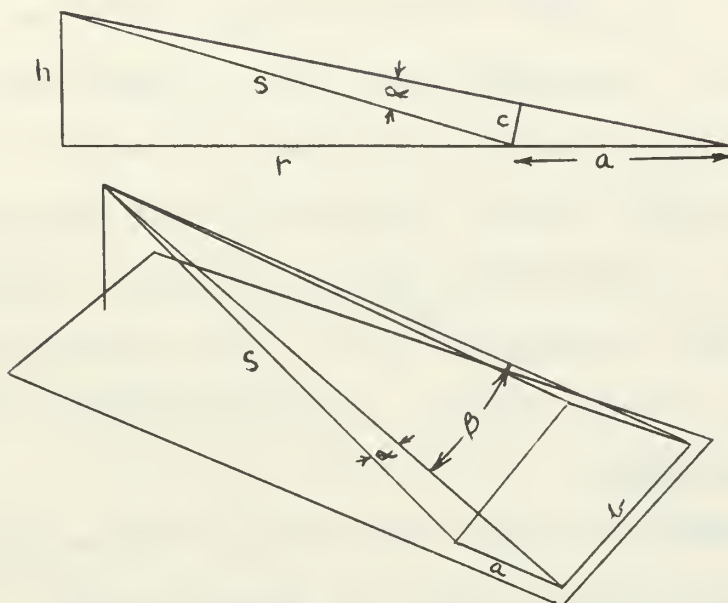


Figure 2. Calculation of Solid Angle

$$\text{Solid Angle} = \alpha \beta$$

$$\alpha = c/s, \quad \beta = b/s$$

$$\text{but } c/a = h/s$$

$$\text{thus } c = ah/s$$

$$\text{Solid Angle} = abh/s^3 = abh/(r^2 + h^2)^{3/2}$$

Since γ was assumed to be proportional to the solid angle,

$$\gamma = \frac{kh}{(h^2 + r^2)^{3/2}}$$

where k included all factors such as meteorological visibility, etc.

Assuming further that in the majority of cases r is much larger than h , then

$$\gamma = \frac{K n}{13}$$

2. Lateral Range

When the observer and the target are on their straight courses at constant speeds for a long time before and after their closest point of approach the probability of detection may be shown to be a function only of the distance at closest point of approach. This distance is called the lateral range, and is denoted as x . This probability of detection, $p(x)$, plotted against lateral range, is called the lateral range curve.

Twice the area under the lateral range curve is defined as effective search width (or Sweep Width),

$$W = 2 \int_0^{\infty} p(x) dx \quad (6)$$

Koopman shows that:

"The effective search width is twice the range of a definite range law of detection which is equivalent to the given law of detection in the sense that each of the two laws detects the same number of uniformly distributed targets of identical velocity."

Thus, for the definite range law of detection $p(x) = 1$ if $x \leq R$, and $p(x) = 0$ if $x > R$, so that $W = 2R$. To find W for the inverse cube law, first $p(x)$ may be shown to be

$$p(x) = 1 - e^{-\frac{2kh}{\omega x^2}} \quad (7)$$

where w is searcher's speed.

From (6),

$$W = \int_{-\infty}^{\infty} \left(1 - e^{-\frac{2kh}{\omega x^2}}\right) dx \quad (8)$$

$$= 2 \sqrt{\frac{2\pi kh}{\omega}} \quad (9)$$

3. Random Search

To find the probability of detecting a target known to be in an area A , where both searcher and target are moving over the ocean in complicated paths, the situation called random search may be considered. This requires the following assumptions:

a. The target's position is uniformly distributed in A , given it has not been detected

b. The observer's path is random in A in the sense that it can be thought of as having its different (not too near) portions placed independently of one another in A .

c. W is small with respect to the area A .

If the searcher's path, of length L , can be considered to be composed of n separate and equal portions of length L/n , then the probability that the target be detected in any one path is WL/nA . The probability that the

target not be detected at all, then is

$$p = 1 - \left(1 - \frac{WL}{nA}\right)^n \quad (10)$$

and for large n ,

$$p = 1 - e^{-WL/A} \quad (11)$$

This is the formula of random search.

4. Parallel Sweeps

The most common method of non-random searching is one which uses a series of straight parallel sweeps a distance S (or track spacing) apart, where the position of the target is fixed with relation to the sweeps. Let the target be uniformly distributed in an area of size A . Search and Screening gives the following result for $P(L)$, the probability of detecting with path length $L=A/S$.

(1) Definite Range Law

Since detection will surely occur if the target is within the detection range $W/2$, then the probability of detection is equal to the coverage factor W/S .

Thus,

$$\begin{aligned} p &= WL/A & L \leq A/W \\ p &= 1 & L > A/W \end{aligned} \quad (12)$$

(2) Inverse Cube Law

$$p = \operatorname{erf} \left(\frac{\pi \sqrt{2m}}{S} \right) = \operatorname{erf} \left(\frac{\sqrt{\pi}}{2} \frac{WL}{A} \right) \quad (13)$$

(3) Uniform Random Search

From (11),

$$p = 1 - e^{-WL/A}$$

or when $S=L/A$,

$$p = 1 - e^{-W/S} \quad (14)$$

The three probabilities using parallel sweeps are shown in Figure 3.

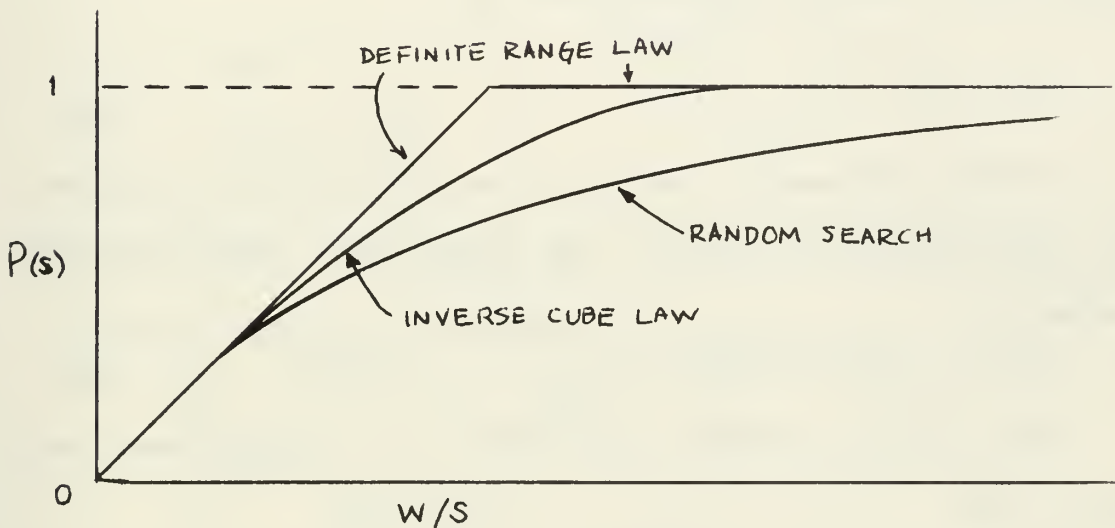


Figure 3. Probability of Detection

B. DISTRIBUTION OF SEARCH EFFORT

1. General

Another result in Search and Screening involves the definition of search effort density as a function of (x,y) in A .

If B is the area of a subregion in A , and L is the

length of the observer's path in B, then the expression L/B is defined to be the observer's track density in B. As B becomes very small (approaches a point (x,y)) the search density $\phi(x,y)$ is the limit of WL/B , or $Wl(x,y)$, where

$$\text{and } \iint_A l(x,y) dx dy = L \quad (15)$$

$$\iint_A \phi(x,y) dx dy = WL = E \quad (16)$$

Thus if $\phi(x,y)$ is applied at (x,y) , the probability of detecting a target located there is

$$p = 1 - e^{-\phi(x,y)} \quad (17)$$

Given the search density function $\phi(x,y)$ and the target's distribution $p(x,y)$, the probability of detecting the target is

$$P(\phi) = \iint_A p(x,y) (1 - e^{-\phi(x,y)}) dx dy \quad (18)$$

The $\phi(x,y)$ which maximizes $P(\phi)$ is shown by Koopman to be

$$\phi(x,y) = \log \frac{p(x,y)}{a \cdot b} \quad (19)$$

when (x,y) is in A' , and

$$\phi(x,y) = 0 \quad (20)$$

when (x,y) is not in A' ,

where A' denotes that portion of A in which the expression (19) is non-negative. The value of b is determined by using equation (16).

2. Normal Target Distribution

If the target's distribution is a bivariate circular normal distribution about a point $(0,0)$ in a cartesian coordinate system,

$$p(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{r^2}{2\sigma^2}}, \quad r^2 = x^2 + y^2 \quad (21)$$

then the search effort density which maximizes $P(\varphi)$ is

$$\varphi(x,y) = \frac{a^2 - r^2}{2\sigma^2} \quad r \leq a \quad (22)$$

and

$$\varphi(x,y) = 0 \quad r > a \quad (23)$$

Thus letting a be the radius r at which $p(x,y)$ assumes the critical value b ,

$$Ab = \pi a^2, \quad b = \frac{1}{2\pi\sigma^2} e^{-\frac{a^2}{2\sigma^2}} \quad (24)$$

where

$$a = \left[\frac{4\sigma^2 E}{\pi} \right]^{\frac{1}{4}} \quad (25)$$

The form of this equation is an inverted parabola of revolution with its center at $(0,0)$ with a maximum value of $a^2/2\sigma^2$.

IV. THE UNIFORM COVERAGE SQUARE SEARCH

Although (19) gives the "optimum" search effort distribution, this optimum distribution is difficult to achieve in practice. Flying in a large circular area with a continuously varying effort is no simple navigational task. Much easier is the common practice of (1) defining a square area with its center at the center of the target's distribution and (2) conducting a regular search of uniform density throughout this area. If the target is not found, then (3) the area is expanded and the search repeated. Although a single search of this type does not conform to the parabolic optimum search effort distribution, a series of them, each larger than the one before, may be a very good approximation.

The most important advantage of this plan is its ease of navigation, allowing the pilot(s) free time to look for the target.

A. THE PROBLEM

The problem was to determine the optimum size of a square area within which a uniform search with parallel sweeps is to be conducted.

B. TERMS

The terms and definitions in the Search and Rescue Manual differ from those in Search and Screening. In the Search and Rescue Manual, probability of detection is used only for the probability of detection with parallel sweeps, (given a uniform target distribution within the search area). In order to avoid confusion, the following terms are defined:

- P - Probability of Success - The probability that on a given search the target will be found.
- p - Location Probability - The probability that a target is within a specified area.
- d - Probability of Detection - The probability of detecting a uniformly distributed target given parallel sweeps.
- W - Sweep Width - The effective search width of the searcher; the area under the lateral range curve.
- S - Track Spacing - The mean distance between adjacent parallel sweeps of the searcher.
- L - Path Length - The total number of miles flown by the searcher within the search area.
- c - Probable Error of Position - Probable error of the target's position from datum; given a normal distribution, $c=1.18 \times$ standard deviation of the target's distribution.
- R - Search Radius - The search radius is defined as one-half the side of a square

search area.

C. THE SOLUTION

1. The Objective

The objective is to maximize the Probability of Success P , where the detection function for a uniformly distributed target known to be in the area is defined as $d(W,L,R,x,y)$. P is expressed as

$$P(W,L,c,R) = \int_{-\infty}^{+\infty} p(x,y) d(W,L,R,x,y) dx dy$$

For a uniform search, the probability of detection is constant and equal to $d(W,L,R)$ inside the search area A , and is zero outside, (given uniform visibility and other factors), and so $d(W,L,R)$ can come out of the integral:

$$P(W,L,c,R) = d(W,L,R) \int_A p(x,y) dx dy$$

It is convenient to choose x and y as distances in a cartesian coordinate system with the target's most likely position (datum) at $(0,0)$.

2. Calculation of Individual Terms

Based on the inverse cube law for parallel sweeps,

Koopman derives the following expression for probability of detection, from (13):

$$d(s) = \operatorname{erf} \left(\frac{\sqrt{\pi}}{2} \frac{W}{s} \right)$$

$$\text{where } S = A/L = (2R)^2/L.$$

This is equivalent to the "First Search" probability of detection given in the National Search and Rescue Manual.

The location probability, p , is given by the formula for the circular bivariate normal distribution:

$$p(R) = \int_{x,y=-R}^{x,y=+R} \frac{1}{2\pi\sigma} e^{-\frac{x^2 + y^2}{2\sigma^2}} dx dy$$

Where R defines a square centered at $(0,0)$ with sides $=2R$.

Figure 4 is a graph of this function, along with a similar curve showing the cumulative probability for a circle with radius R . Since the square area is actually larger (it is circumscribed about the circle) its probability for any radius R is greater. However, if these cumulative probabilities are plotted against the area of the search, the probability for a square will be slightly less than for a circle (see figure 5). Although there is some loss of efficiency in searching a square instead of a circle, this loss is very minimal, about 1%.

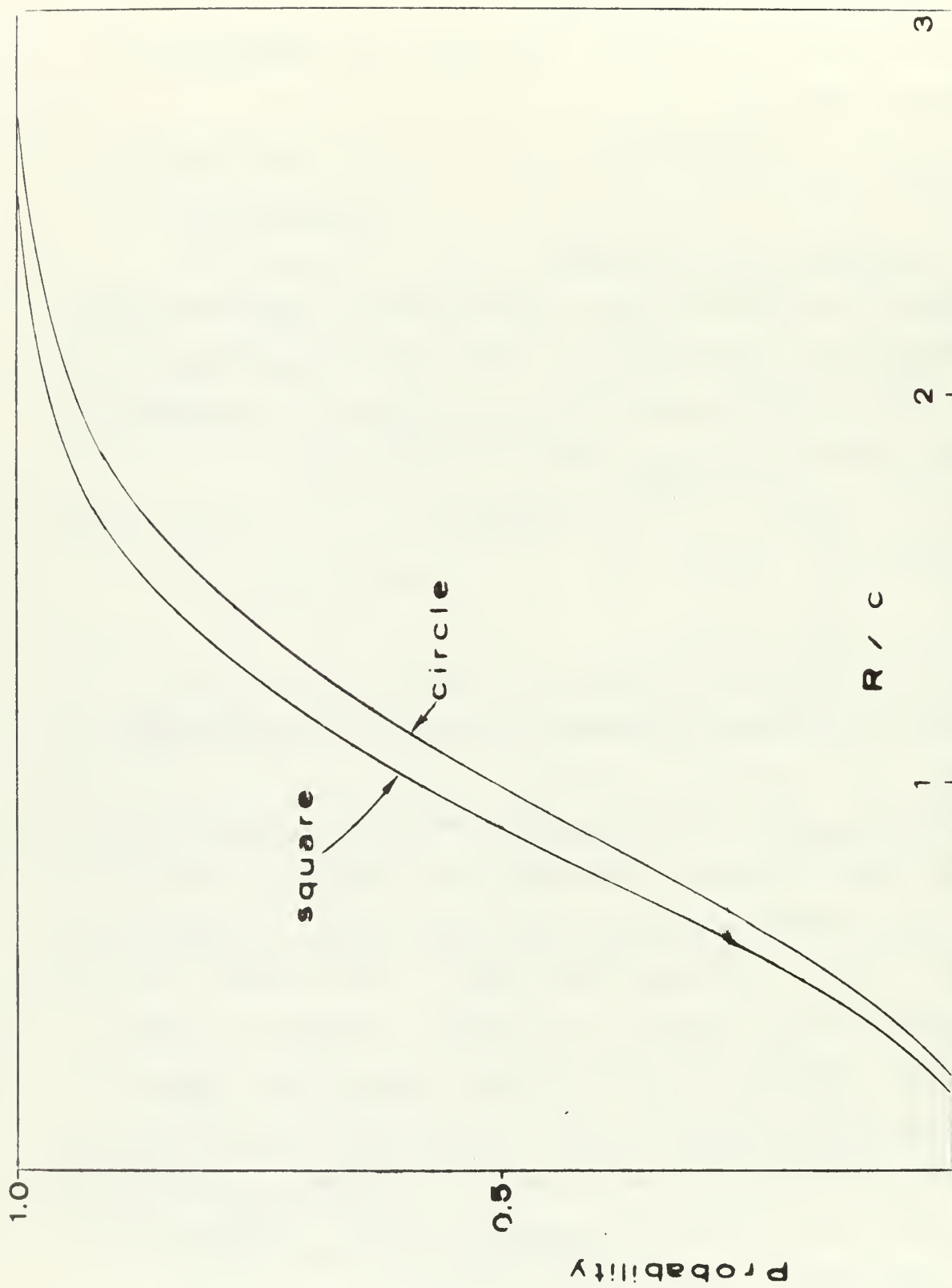


Figure 4. Cumulative Probability for Circle with Radius R and for Square with Sides equal to $2R$.

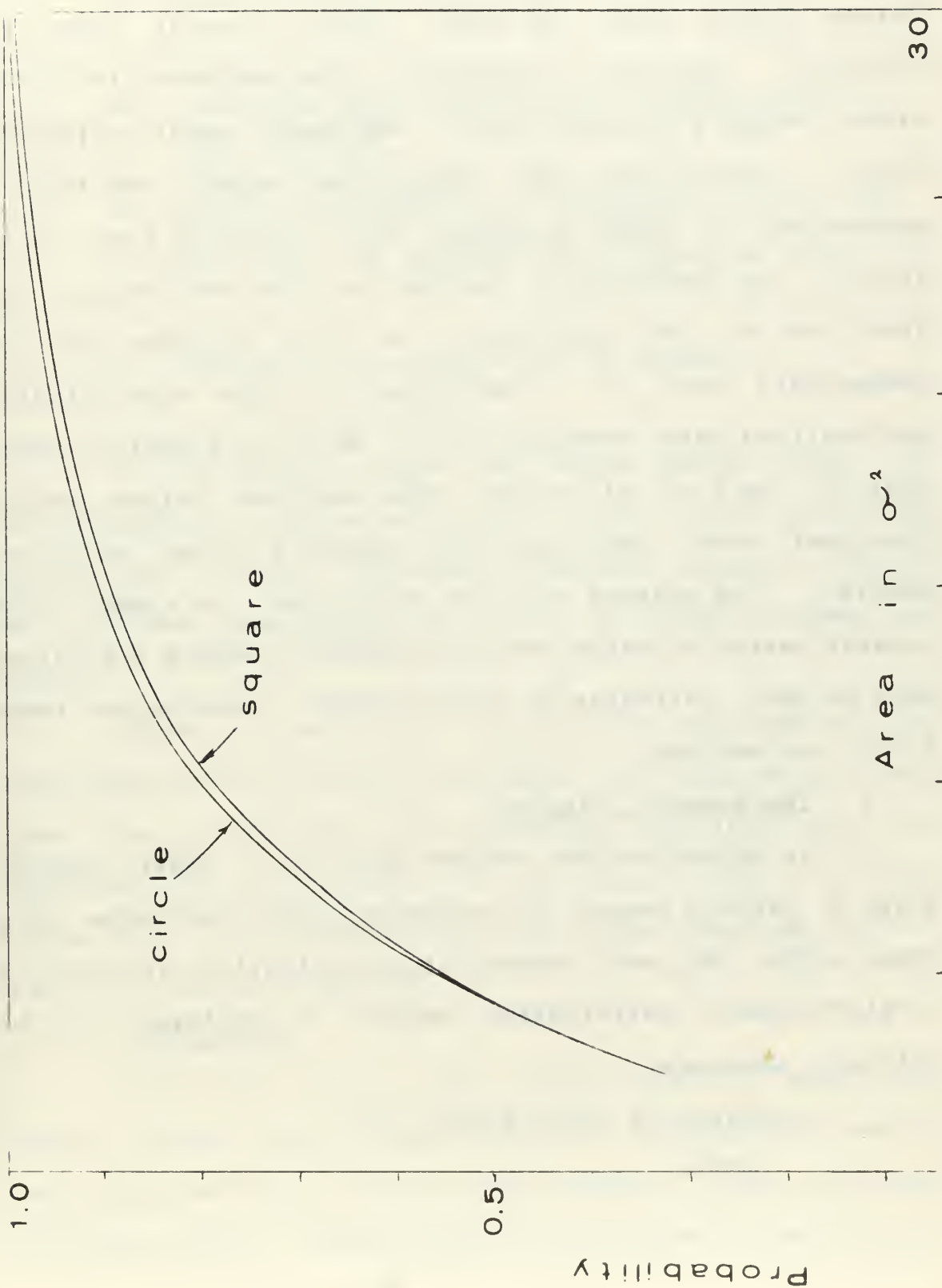


Figure 5. Cumulative Probability for Circle and Square Plotted against Area.

NOTE: Although the standard deviation is the commonly accepted measure of variability, the National Search and Rescue Manual uses the term, "Total Probable Error of Position". Its value is computed using estimates for drift error, target's position error, and search craft navigation error. These errors are squared and added, and then a square root is taken to produce Total Probable Error. This term is not specifically defined in that publication, so that one of the objectives of this solution was to demonstrate that it is equivalent to the statistically well-defined term 'Probable Error', which is a median error: that is, half of all errors have absolute values greater than that error, and half have absolute values which are smaller. The absence of this definition is a gap in the present search planning process, because planners are called upon to make estimates of errors without knowing how these errors are defined.

3. The General Solution

To determine the optimum size for a square search, given a certain amount of searching miles available (L), sweep width (W), and probability distribution ($p(x,y)$), a straightforward maximization method is employed in the following sequence:

- a. Determine total effort, E.

$$E=W \times L$$

b. Choose some arbitrary initial search radius, x .

c. Determine the search area, A , for this x :

$$A = 4x^2$$

d. Determine effort density for a uniform search:

$$\frac{WL}{A} \left(= \frac{W}{S} \right)$$

e. Determine probability of detection d from (13).

f. Determine the probability p from (21) with $R =$

x .

g. Determine the probability of success,

$$P(x) = p(x)d(x).$$

h. Increase x by Δx and repeat calculations. If $P(x)$ increases, continue adding Δx until a local maximum is encountered. If $P(x)$ decreases initially, reduce x by $2\Delta x$ and continue subtracting Δx until a local maximum is reached.

Since a cumulative probability distribution is continuous and has a slope throughout its range of ≥ 0 , and since the probability of detection function $d(x)$ is continuous with a slope of < 0 , the function $P(x) = p(x)d(x)$ can be shown to be unimodal, and so a local maximum in $P(x)$ will be an absolute maximum.

4. Application

The first use of this method was to check the National Search and Rescue Manual's recommended search planning guidelines to see if they produce square searches of optimum sizes. These guidelines are given in the form of

'Safety Factors', or search radii, for repeated searches, as multiples of Total Probable Error of Position, e.g.,

Search	Safety Factor
1	1.1
2	1.6
3	2.0
4	2.3
5	2.5

As far as effort density is concerned, there are two recommendations given in the SAR Manual. One is for a track spacing equal to sweep width, for urgent cases, and the other for a track spacing equal to twice the sweep width, for less urgent searches. Both of these recommendations were tested.

The approach used was:

- a. Set some arbitrary value for W
- b. Set $S=W$ so that $WL/A. =1$.
- c. Find R from "safety factor" table for the appropriate search (starting at 1).
- d. Find path length, L:

$$L = \frac{4 R^2}{S}$$

- e. Beginning at $x = R$, and with W and L above, use the general solution process described in paragraph 3. to

find x' , the optimum search radius for that path length.

f. Assuming that the optimal search is executed unsuccessfully, reevaluate the target's distribution $p(x)$ (see Para. 5.) and repeat the process from c. above. After five successive searches have been computed, stop the computation.

g. Compare the resulting five optimum sizes with the sizes recommended in the Safety Factor table from the Search and Rescue Manual.

5. Bayesian Analysis

Bayes' Law of Probability says that an estimate of the probability of a hypothesis can and should be revised on the basis of the outcome of a related event. In the case of search theory, the hypothesis is that the target is inside a given area. A search is conducted, and the event is either the detection or the non-detection of the target. This event should revise the initial estimate of the probability that the target was in the area. Of course, if the event is detection, the new probability that the target is in the area is 1. If the event is non-detection, then Bayes' formula must be used to calculate the new probability.

1. Example

The probability that a target is in a certain search area has been determined to be 50%, and a search is conducted in this area with a uniform probability of detection of 50%. The resulting probability of success is .5

$\times .5 = .25$ or 25%.

For the use of Bayes' formula, the following terms are defined:

- A The hypothesis that the target is in the area.
- $\bar{A}$ The hypothesis that the target is not in the area.
- D The event of detection.
- $\bar{D}$ The event of non-detection.

Then

$$P(A|D) = \frac{P(A) \cdot P(D|A)}{P(A) \cdot P(D|A) + P(\bar{A}) \cdot P(D|\bar{A})}$$

When the target is detected:

$$P(A|D) = \frac{0.5 \times 0.5}{0.5 \times 0.5 + 0.5 \times 0.0} = 1.0$$

as expected. If the target is not detected, the new probability would be

$$\begin{aligned} P(A|\bar{D}) &= \frac{P(A) \cdot P(\bar{D}|A)}{P(A) \cdot P(\bar{D}|A) + P(\bar{A}) \cdot P(\bar{D}|\bar{A})} \\ &= \frac{0.5 \times 0.5}{0.5 \times 0.5 + 0.5 \times 1.0} = \frac{1}{3} \end{aligned}$$

Whereas the target had a 50% a priori probability of being in the search area, its new, or a posteriori probability of being in the area is 33.3%.

For the solution in paragraph 4., the entire probability distribution of the search object was reevaluated between successive searches. This was done for $p(x)$ inside the search area by

$$p'(x) = \frac{p(x)(1-d)}{(1 - p(R)d)} \quad (26)$$

and for $p(x)$ outside the search area by

$$p'(x) = \frac{(p(x) - p(R))}{(1 - p(R)d)} + p'(R) \quad (27)$$

where R is the radius of the search conducted.

In order to illustrate the general form of the probability distributions between searches, a function was used which is similar to a density function. This function, $f(x)$ was defined to be

$$f(x) = \left(\frac{d(p(x))}{dx} \right) \left(\frac{1}{8x} \right) \quad (28)$$

where x is the measure of radius, or again, one-half of one side of a square, and $8xdx$ is the differential of

area (Figure 6).

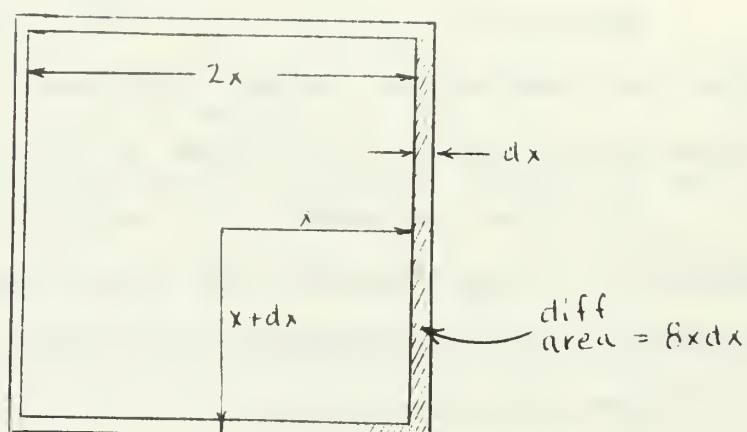


Figure 6. Derivation of Density Function for Square Area

Curve 1 in Figure 7 is the density function before any searching is done, as derived by (28) from (21). Curves 2 through 5 are these functions after successive searches.

Figure 8 is a similar set of curves showing the cumulative probability distributions.

6. Results

This method (from 4.) gives the following optimum searches:

Search	Optimum Radius	Safety Factor
1	1.08	1.1
2	1.64	1.6
3	2.07	2.0

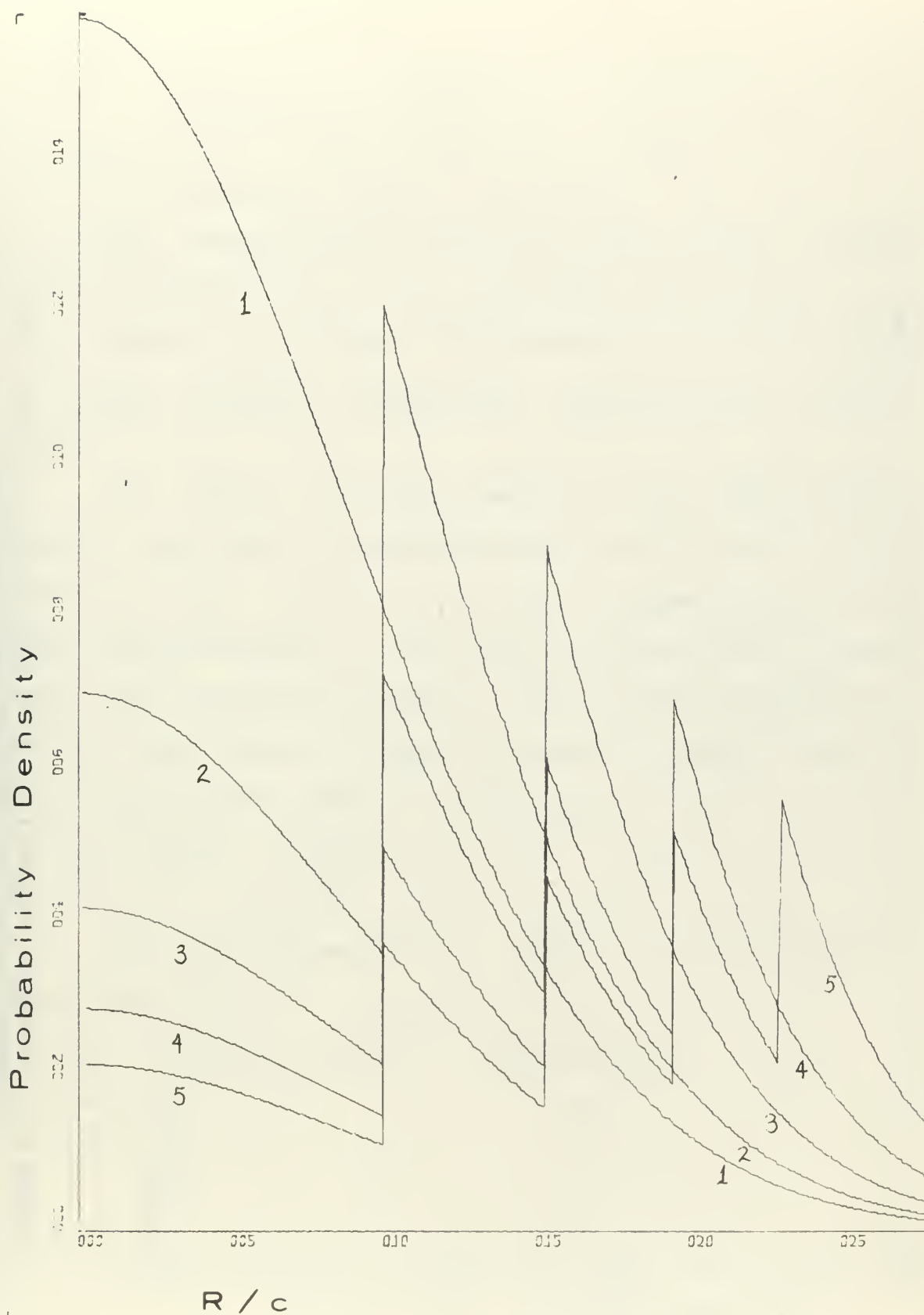


Figure 7. Probability Density with Application of Bayes' Law Between Successive Optimum Square Searches.

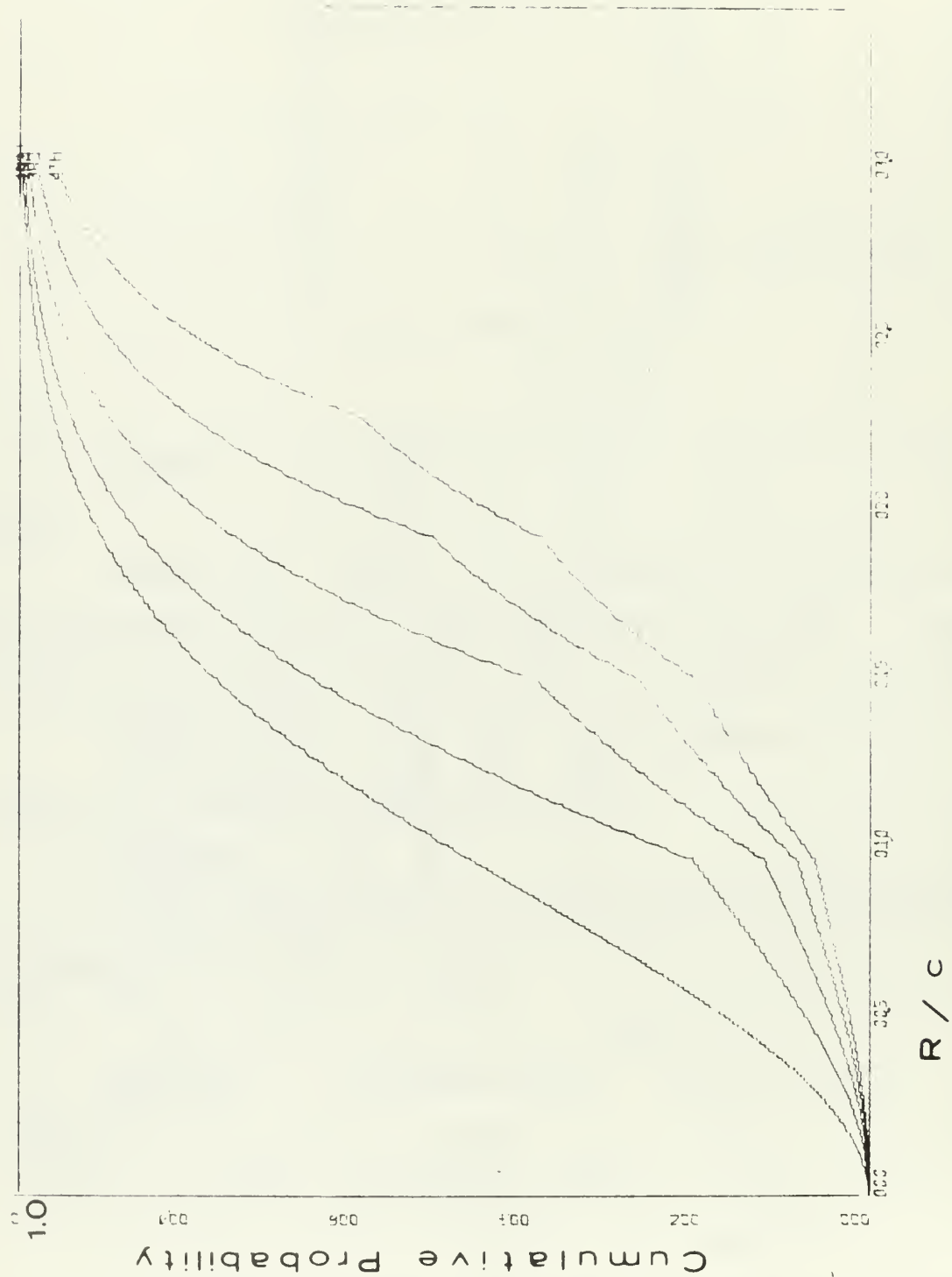


Figure 8. Cumulative Probability with Application of Bayes' Law
Between Successive Optimum Square Searches.

4	2.43	2.3
5	2.74	2.5

Since these results were very close to the 'Safety Factors' listed above, it was concluded that (1) the safety factors were originally good calculations, and (2) they were calculated using the mathematical definition of probable error.

It should be noted, however, that these safety factors are close to optimum search radii only for the condition where track spacing equals sweep width. The second recommendation, track spacing equals twice sweep width, does not produce anywhere near optimum search areas. When a track spacing S' equal to twice the sweep width is used, the new path length L' is given by

$$L' = \frac{4R^2}{S'} = \frac{4R^2}{2W} = \frac{1}{2} L$$

For this new path length, optimum search sizes were found to be:

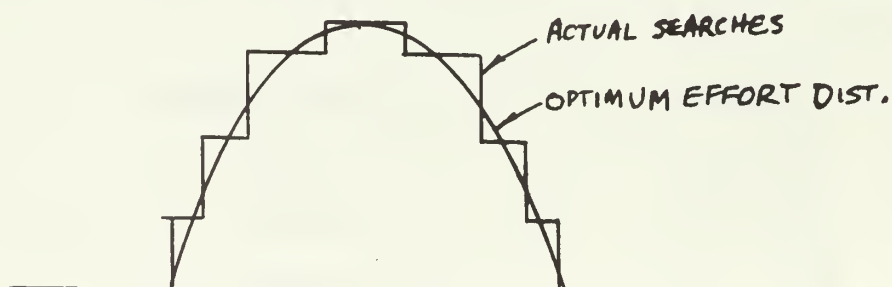
Search	Optimum Radius
1	0.85
2	1.30
3	1.66
4	1.95
5	2.20

When there is less search effort available the size of the search area as well as the effort density should be reduced. The SAR Manual gives no guidance as to how much the area should be reduced with a given amount of available effort. Conversely, there is no indication as to how excess search resources should be used, if such a condition should exist.

What is needed is some way for the search planner to determine the optimum search configuration directly from the amount of search effort available.

D. THE GENERAL CASE

Assume that a series of optimum square searches, each larger than the preceding one, is a good approximation of an optimum search effort distribution. Consider all the searches of the series combined into one search effort, so that the search effort density $\phi(r)$ assumes a step function which is close to the ideal effort density.



The radius r of the combined search is equal to the

radius of the last (and the largest) individual search in the sequence.

If the search had been a circular one, and if the effort density had conformed to the optimum, the expression for this radius would be

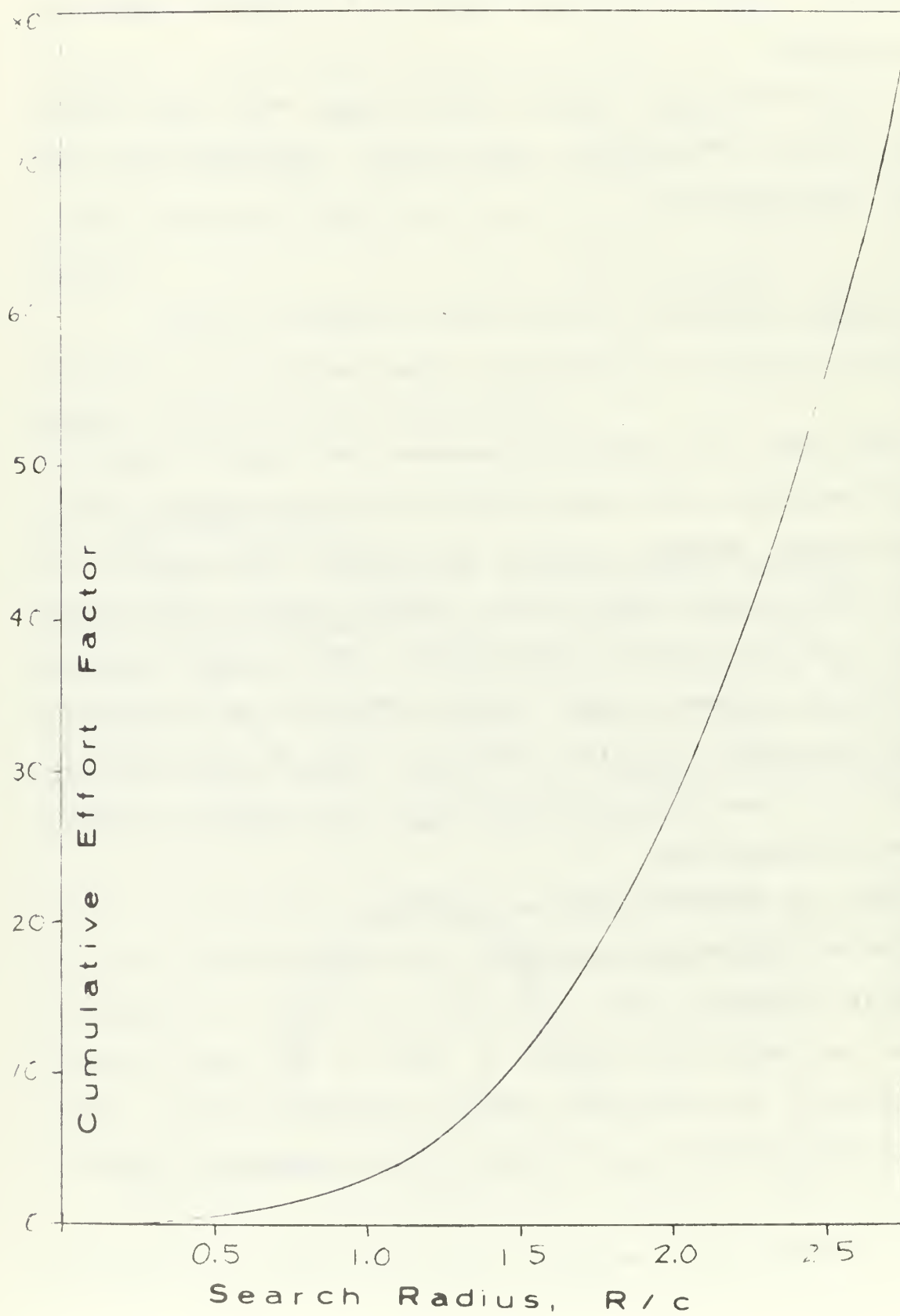
$$a = \left[\frac{4 \sigma^2 E}{\pi} \right]^{\frac{1}{4}}$$

But since the search is composed of a small number of square searches, this same formula is not expected to apply. There should, however, be some way to approximate a function which will define the optimum radius based on available effort and the target's distribution. The simplest way to do this is to compute total search effort for a few optimum square searches, plot the radius of each of the searches against the cumulative search effort, and attempt to smooth a curve through them.

This was done for the ten searches (five at $W = S$ and five at $W = 2S$) calculated above, and the resulting curve is shown in Figure 9. Just as radius is in terms of probable error, so are the factors W and L of total effort 'normalized' by dividing each by probable error. Thus 'normalized' effort is a multiple of the square of probable error.

It should be cautioned that the curve is only an

Figure 9. Optimum Size of Square Search based on Cumulative Normalized Effort Factor.



approximation, and will not be valid if the effort available for a single search is very large. Thus if a search is computed which shows a coverage factor (W/S) greater than 1.8, then the results of the curve will not give an optimum search, and some other method will be required. Again, the effort plotted is cumulative, so that all the effort exerted in earlier searches must be added to the effort available for the present search before entering the table.

Example: One 150-knot aircraft is available for six hours of searching; the total probable error of position has been calculated to be 31.9 miles, and W is estimated at 10 miles.

Total effort then is found as follows:

$$E = 150\text{kts} \times 6\text{hrs} \times 10\text{miles}(W)$$

$$= 9000 \text{ square miles}$$

In terms of probable error, (c=31.9)

$$E(\text{normalized}) = 9000 / (31.9 \times 31.9) = 8.9$$

From the graph, $r = 1.4$,

$R = 1.4 \times c = 44.6$ miles, or 89.2 miles on a side, and

$$S = 4 \times R \times R / L = 8.75 \text{ miles.}$$

If the target is not found on the first search, and a second is to be conducted, the amount of available effort is calculated for the second search. The normalized effort for this search must be combined with all previously expended effort before entering the graph. Thus if $E(\text{normalized})$ for the second search is calculated to be 10.0, the graph should be entered with a figure of $10.0 + 8.9$ or 18.9 to find the radius of the second search. Each search area will be larger than the preceding one.

This decision curve should prove to be a more flexible tool for search planning than the Safety Factor table, since it provides a continuous range of search radii for different amounts of effort available.

V. THE SECTOR SEARCH

There is one search pattern in general use which does effect a greater concentration of effort at the center of the search area, and that is the sector search. This search pattern is executed by a series of sweeps crossing over the center of the search area at various angles. These sweeps are connected at their endpoints by chords flown near the perimeter of the area. This pattern covers a circular area and, perfectly navigated, produces a track as shown in Figure 10.

A. SEARCH EFFORT DISTRIBUTION

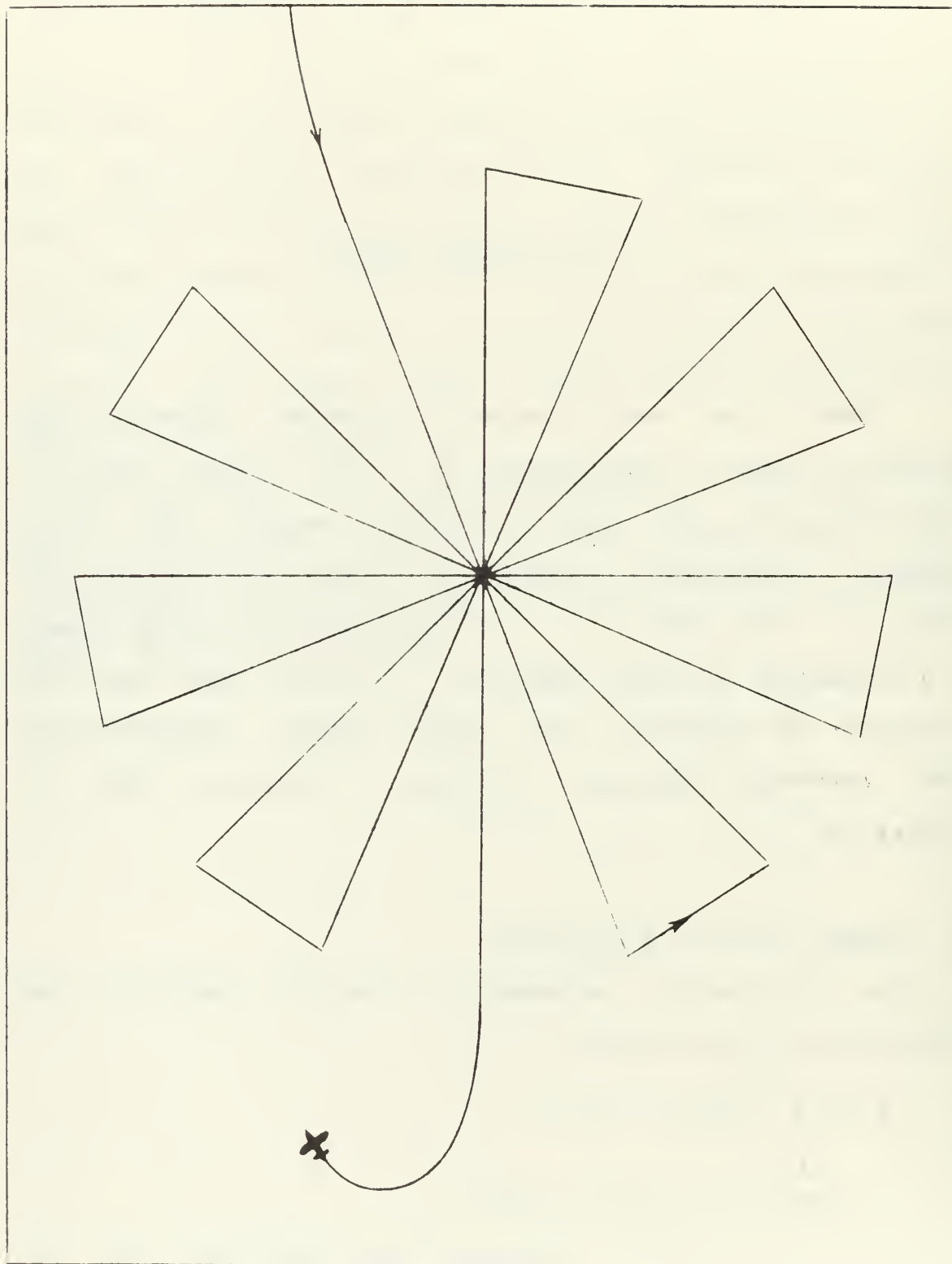
The total effort expended in a sector search can be expressed by the integral

$$E = \int_0^{\infty} \phi(r) 2\pi r dr$$

where R is search radius

r is the distance from the center of the search

Figure 10. The Sector Search



$\phi(r)$ is the search effort density at some distance r .

This density function $\phi(r)$ is simply W times the number of paths which intersect a circle of radius r , multiplied by dr to give total path length between r and $r+dr$, and then divided by the area between r and $r+dr$. Thus

$$\phi(r) = \frac{Wn \, dr}{2\pi r \, dr} = \frac{Wn}{2\pi r} \quad (19)$$

Then,

$$E = WL = \int_0^{\infty} \frac{Wn}{2\pi r} 2\pi r \, dr = WnR \quad (30)$$

and,

$$L = nR$$

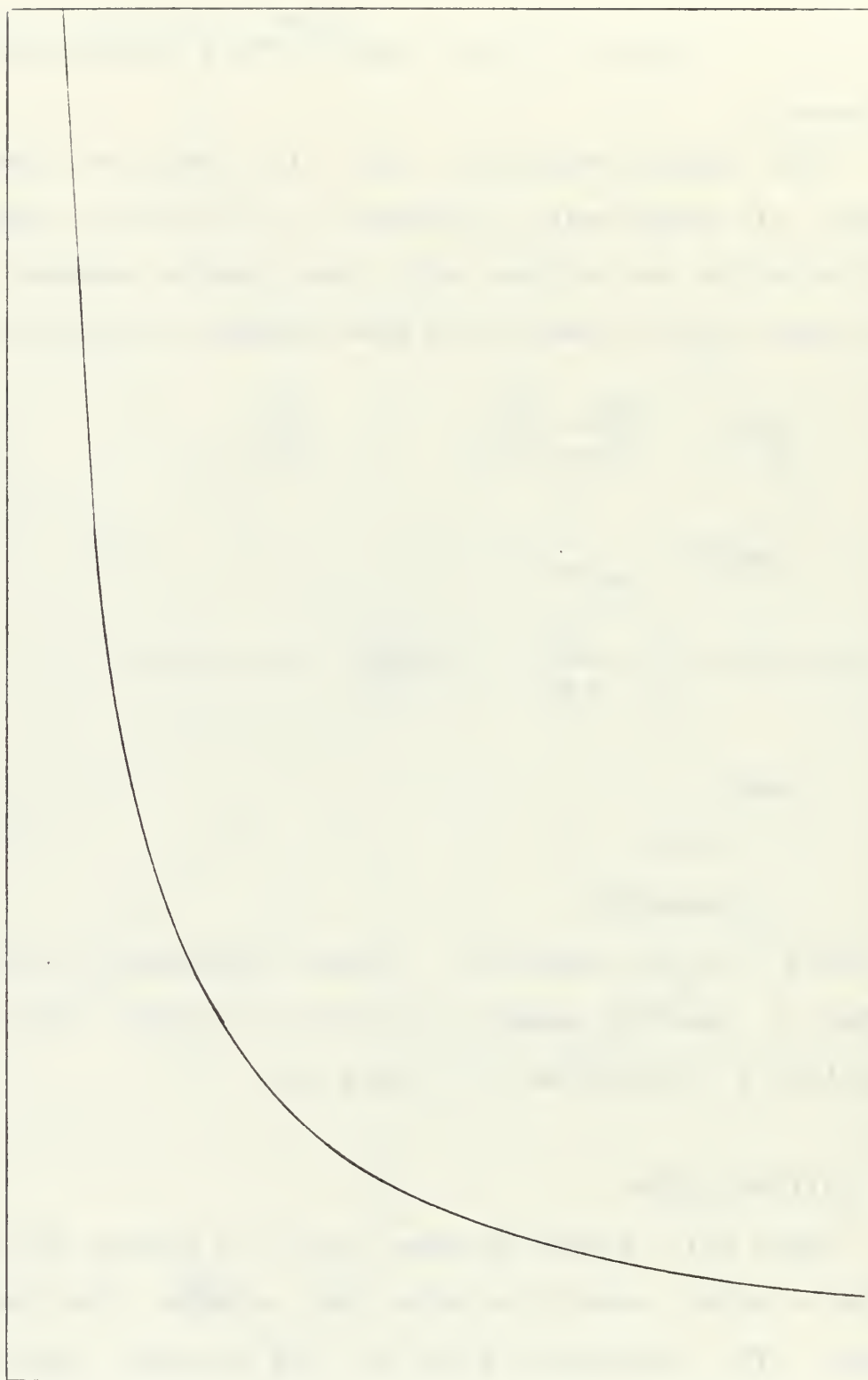
as expected.

Here n is the number of 'spokes' produced, or twice the number of complete sweeps across the circle. This density function is illustrated in Figure 11.

B. PATTERN ERROR

There will always be some error in flying any search pattern, which should be taken into account for the sector search. The navigation error of the searcher has already been taken into account when computing the Total Probable Error of Position. The pattern error, however, can be

Search Effort Density



Distance from Center, R

Figure 11. Search Effort Density in a Perfectly Navigated Sector Search.

different from this navigation error. Whereas navigation error considers only the searcher's ability to find the datum point in order to define the search area, pattern error, as it is used here, describes his flying error within the area. If, once the searcher finds what he thinks to be datum, he drops a smoke float or some other marking device, then his pattern error will be much smaller than his navigation error. Conversely, if when arriving in the search area he stops referring to his navigation aids and relies thenceforth on dead reckoning only, his pattern error will be greater than his navigation error.

Although by its nature, a flying error is bivariate (like the error of target position) a simplification was made. Since the pilot is flying long sweeps which have their endpoints relatively far away from the area of concern (the center of the area), only his lateral position error (which is univariate) was considered.

It was assumed for this analysis that the lateral component of pattern error is nearly normal, and that it can somehow be calculated or estimated.

The expression for the total effort expended in flying the spokes of a sector search is

$$E = 2 W_n \int_0^R \int_0^{\frac{\pi}{2}} \frac{1}{\sqrt{2\pi} \sigma_p} e^{-\frac{r^2 \sin^2 \alpha}{2 \sigma_p^2}} r dr d\alpha \quad (31)$$

(r sin α = Lateral range)
(σ_p = σ Lateral pattern error)

The derivative of this expression with respect to r was used as the search effort density function for a sector search with pattern error.

$$\psi(r) = \frac{2\sqrt{m}}{\pi} \int_0^{\pi/2} \frac{1}{\sqrt{2\pi} \sigma_r} e^{-\frac{r^2 \sinh^2 x}{2\sigma_r^2}} dx \quad (32)$$

For the analysis this basic density function was computed with sweep width, standard deviation of pattern error, and number of spokes all equal to 1. To find the density function for any particular set of parameters, the density is multiplied by W and n , and the horizontal scale is multiplied by the standard deviation of the pattern error.

C. OPTIMUM SECTOR SEARCH

The plot of this density function is found in Figure 12. An inspection of this plot will show that it is close to a quadratic function out to $r = 3$ standard deviations. Since Koopman's ideal search is a quadratic, some guidance was provided as to the optimum radius for the sector search, based on the pattern error. It was then necessary to adjust the number of spokes to arrive at the ideal effort expenditure to match this radius. Koopman's ideal search effort density is a function of search radius and target's position error:

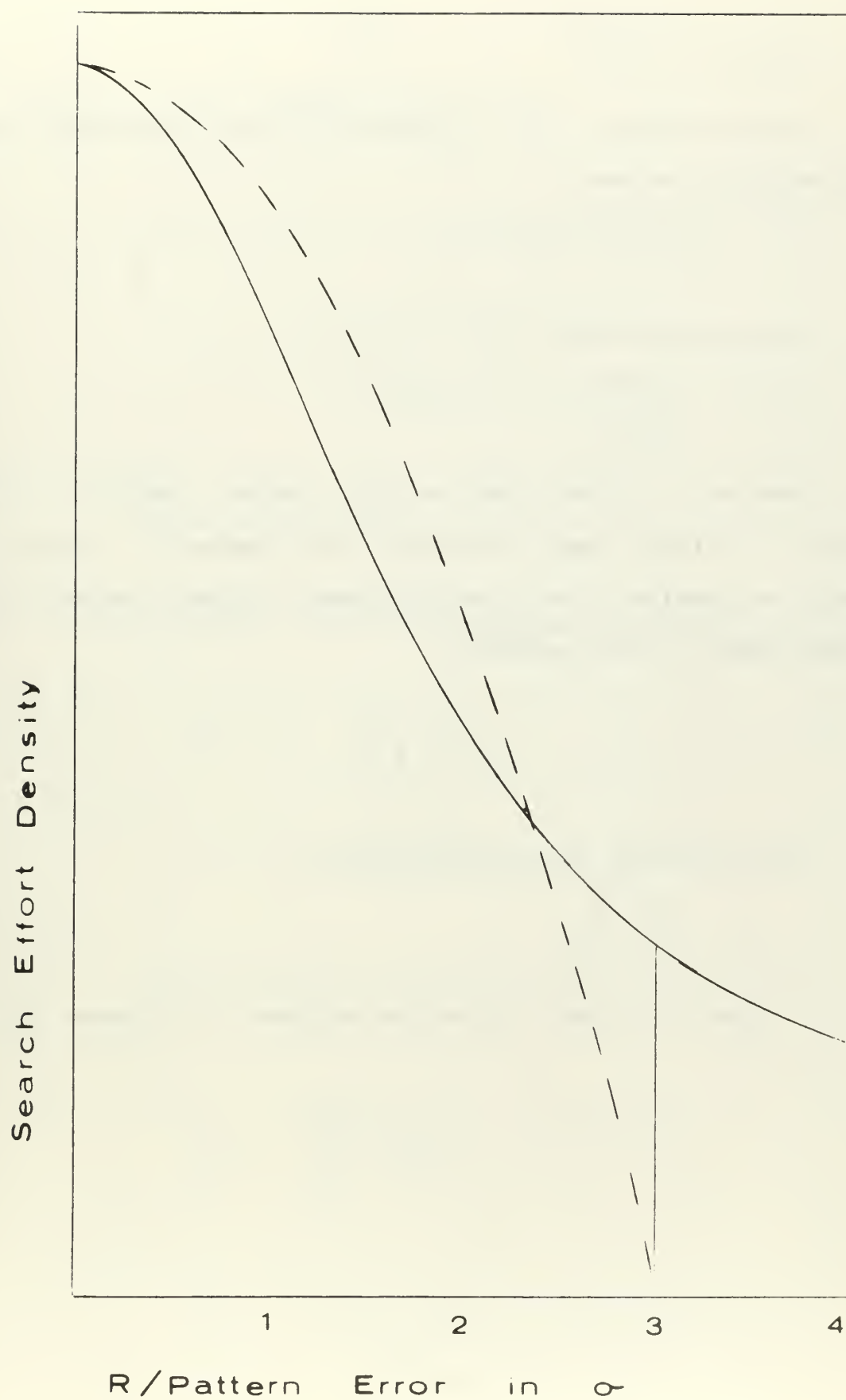


Figure 12. Search Effort Density in a Sector Search with Pattern Error.

$$\varphi(x,y) = \frac{a^2 - r^2}{2\sigma^2} \quad \begin{array}{l} r \leq a \\ r > a \end{array}$$

$$= 0$$

and the radius is a function of target position error and available effort:

$$a = \left[\frac{4\sigma^2 E}{\pi} \right]^{\frac{1}{4}}$$

Solving for effort, E:

$$E = \frac{a^4 \pi}{4\sigma^2} = WL$$

However, in the case of the sector search, L, the number of miles flown, is simply the number of spokes, n, times the radius. The chords flown at the perimeter are disregarded in this analysis:

$$L = a \times n$$

Substituting, and solving for n:

$$n = \frac{a^3 \pi}{4\sigma^2 W}$$

Ideally, then, since the optimum a is known to be

close to three standard deviations:

$$m = \frac{27 \sigma_p^3 \pi}{4 \sigma^2 W} \quad (33)$$

or, when all errors are expressed as probable errors,

$$c_p = .67 \sigma_p$$

$$c = 1.18 \sigma$$

$$m = \frac{4.95 c_p^3}{W c^2} \quad (34)$$

Table 1 is a tabulation of this function for various conditions of total probable error of position c , and pattern error. The n derived from the table must be divided by sweep width W to obtain number of spokes.

From the example of the sunken fishing boat, $c = 31.9$ and $W = 10.0$ miles. If the searcher's pattern error were 13 miles, then search radius R would equal 58.5 miles.

Interpolating in the table, $n = 100$, then

$$\text{Number of spokes} = 100/10 = 10$$

and the angle between adjacent search legs $= 360/10 = 36$ degrees.

Total search miles flown would be

$$10 \times 58.5 = 585$$

plus the amount of flying at the perimeter (in order to fly the pattern, the aircraft must traverse a distance somewhat less than one-half the circumference of the area):

$$585 + 58.5 \times \pi = 585 + 184 = 770 \text{ miles.}$$

This table for sector search will not be useful until an accurate means of predicting pattern error is found. The function given in (34) is extremely sensitive to pattern error, and thus accuracy for this parameter is required to use the table.

Even if it is not actually used to determine the parameters of a sector search, the table does serve to

SECTOR SEARCH

TABLE OF OPTIMUM RADIUS AND NUMBER OF SEARCH LEGS

PATTERN ERROR	OPTIMUM RADIUS	POSITION ERROR, C											
		5	10	15	N	X	W	25	30	35	40	45	50
0	5.0	1	0	0	0	0	0	0	0	0	0	0	0
1	4.0	140	3	1	3	7	0	2	1	2	1	1	1
2	3.0	1133	129	5	5	14	0	4	8	13	6	4	3
3	2.0	403	258	4	0	3	1	9	7	19	10	3	2
4	1.8	695	1009	1	5	16	1	16	3	30	14	1	1
5	1.7	1360	1634	7	1	26	1	24	5	45	19	0	0
6	1.6	1870	2407	1	6	37	1	35	8	60	28	0	0
7	1.5	2231	3622	5	1	45	1	44	5	80	38	0	0
8	1.4	2709	4627	1	6	50	1	49	3	95	40	0	0
9	1.3	3212	6077	7	1	55	1	45	5	108	48	0	0
10	1.2	3811	8027	1	6	65	1	45	3	125	53	0	0
11	1.1	4512	10273	5	1	76	1	42	4	148	60	0	0
12	1.0	5312	12815	1	6	87	1	42	8	167	67	0	0
13	0.9	6212	15917	7	1	95	1	45	6	186	72	0	0
14	0.8	7212	19157	1	6	105	1	42	8	205	78	0	0
15	0.7	8312	22927	5	1	116	1	42	5	224	84	0	0
16	0.6	9512	27267	1	6	125	1	42	5	243	89	0	0
17	0.5	10907	32740	7	1	135	1	42	5	262	94	0	0
18	0.4	12828	39322	1	6	145	1	42	5	281	99	0	0
19	0.3	14962	47662	5	1	155	1	42	5	300	104	0	0
20	0.2	16987	57662	1	6	165	1	42	5	319	109	0	0
				7	1	175	1	42	5	338	114	0	0
				1	6	185	1	42	5	357	119	0	0
				5	1	195	1	42	5	376	124	0	0
				1	6	205	1	42	5	395	129	0	0
				7	1	215	1	42	5	414	134	0	0
				1	6	225	1	42	5	433	139	0	0
				5	1	235	1	42	5	452	144	0	0
				1	6	245	1	42	5	471	149	0	0
				7	1	255	1	42	5	490	154	0	0
				1	6	265	1	42	5	509	159	0	0
				5	1	275	1	42	5	528	164	0	0
				1	6	285	1	42	5	547	169	0	0
				7	1	295	1	42	5	566	174	0	0
				1	6	305	1	42	5	585	179	0	0
				5	1	315	1	42	5	604	184	0	0
				1	6	325	1	42	5	623	189	0	0
				7	1	335	1	42	5	642	194	0	0
				1	6	345	1	42	5	661	199	0	0
				5	1	355	1	42	5	680	204	0	0
				1	6	365	1	42	5	699	209	0	0
				7	1	375	1	42	5	718	214	0	0
				1	6	385	1	42	5	737	219	0	0
				5	1	395	1	42	5	756	224	0	0
				1	6	405	1	42	5	775	229	0	0
				7	1	415	1	42	5	794	234	0	0
				1	6	425	1	42	5	813	239	0	0
				5	1	435	1	42	5	832	244	0	0
				1	6	445	1	42	5	851	249	0	0
				7	1	455	1	42	5	870	254	0	0
				1	6	465	1	42	5	889	259	0	0
				5	1	475	1	42	5	908	264	0	0
				1	6	485	1	42	5	927	269	0	0
				7	1	495	1	42	5	946	274	0	0
				1	6	505	1	42	5	965	279	0	0
				5	1	515	1	42	5	984	284	0	0
				1	6	525	1	42	5	1003	289	0	0
				7	1	535	1	42	5	1022	294	0	0
				1	6	545	1	42	5	1041	299	0	0
				5	1	555	1	42	5	1060	304	0	0
				1	6	565	1	42	5	1079	309	0	0
				7	1	575	1	42	5	1098	314	0	0
				1	6	585	1	42	5	1117	319	0	0
				5	1	595	1	42	5	1136	324	0	0
				1	6	605	1	42	5	1155	329	0	0
				7	1	615	1	42	5	1174	334	0	0
				1	6	625	1	42	5	1193	339	0	0
				5	1	635	1	42	5	1212	344	0	0
				1	6	645	1	42	5	1231	349	0	0
				7	1	655	1	42	5	1250	354	0	0
				1	6	665	1	42	5	1269	359	0	0
				5	1	675	1	42	5	1288	364	0	0
				1	6	685	1	42	5	1307	369	0	0
				7	1	695	1	42	5	1326	374	0	0
				1	6	705	1	42	5	1345	379	0	0
				5	1	715	1	42	5	1364	384	0	0
				1	6	725	1	42	5	1383	389	0	0
				7	1	735	1	42	5	1402	394	0	0
				1	6	745	1	42	5	1421	399	0	0
				5	1	755	1	42	5	1440	404	0	0
				1	6	765	1	42	5	1459	409	0	0
				7	1	775	1	42	5	1478	414	0	0
				1	6	785	1	42	5	1497	419	0	0
				5	1	795	1	42	5	1516	424	0	0
				1	6	805	1	42	5	1535	429	0	0
				7	1	815	1	42	5	1554	434	0	0
				1	6	825	1	42	5	1573	439	0	0
				5	1	835	1	42	5	1592	444	0	0
				1	6	845	1	42	5	1611	449	0	0
				7	1	855	1	42	5	1630	454	0	0
				1	6	865	1	42	5	1649	459	0	0
				5	1	875	1	42	5	1668	464	0	0
				1	6	885	1	42	5	1687	469	0	0
				7	1	895	1	42	5	1706	474	0	0
				1	6	905	1	42	5	1725	479	0	0
				5	1	915	1	42	5	1744	484	0	0
				1	6	925	1	42	5	1763	489	0	0
				7	1	935	1	42	5	1782	494	0	0
				1	6	945	1	42	5	1801	499	0	0
				5	1	955	1	42	5	1820	504	0	0
				1	6	965	1	42	5	1839	509	0	0
				7	1	975	1	42	5	1858	514	0	0
				1	6	985	1	42	5	1877	519	0	0
				5	1	995	1	42	5	1896	524	0	0
				1	6	1005	1	42	5	1915	529	0	0

Table 1. Optimum Sector Search. Divide quantity in "N X W" table by Sweep Width to obtain number of search legs.

illustrate that accurate navigation does not necessarily produce the optimum sector search, and that only under the unusual conditions of an extremely accurate estimate of target position is it desirable to reduce pattern error. On the contrary, in most instances, effectiveness may be enhanced by increasing pattern error.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. THE SEARCH PLANNING PROGRAM

It is recommended that the Coast Guard begin immediately to make full use of the Search Planning Program now operational and undergoing testing at the Fleet Numerical Weather Central, Monterey. A guide for users of this program is included as Appendix A.

1. Precautions

The following cautions are appropriate for users of the information provided by this program.

a. Region of Validity.

Because the weather data points used in this program are approximately 200 miles apart, drift calculations provided for areas within 100 miles of shore should be double-checked by hand before using. If hand calculations produce a larger value for total drift, then the hand-calculated answers should be used in lieu of the computer solution.

b. Time of Datum

Weather predictions in the format required for this program are not produced by the Weather Facility for more than 48 hours in advance. Accordingly, users should

avoid requesting plots for time periods beyond 36 hours from the time the request is submitted. If a plot is requested which is later in time than the last computed weather, the information will be provided for that plot and a caution statement will appear in the message reply.

c. Numbers of Initial and Datum Positions

No more than nine initial positions may be entered, and no more than nine datum times will be calculated, in any one run of the program.

The user is encouraged to request whatever number of datum points may be useful to him. Thus if a search is planned for 0800Z, the search planner may wish to request additional data for target position at 1000Z, 1200Z, 1400Z, and 1600Z.

2. Leeway

It is suggested that further experimentation be done in the area of survivor craft leeway to determine the general shape of the leeway function. It is expected that this shape will be close to that of the liferaft drift tables, and to the formula of Witting given in Ref.3.

$$V = k \sqrt{\text{Wind}} \quad (35)$$

and which is used in the time-sharing version of the program for all leeway. This same function is used in both versions to approximate liferaft leeway.

When better data is available, the program at Fleet Numerical can be changed to accomodate the curved leeway function.

3. Testing

It is suggested that a rigorous program of testing and evaluation of the results of the Search Planning Program be initiated. If the program proves to be more accurate than other methods, its contribution to the search planning process, and to oceanographic research in general, will be substantial.

4. Operational Use in the Coast Guard

Although the program will be available to the Coast Guard via the facilities of the Fleet Numerical Weather Central, there are further possible advantages of such a program which are not available through these facilities.

a. Optimum Search Areas

The computer method of solving for optimum searches shown in part IV of this thesis could be added to the Search Planning Program.

b. Other Applications

Computation of on-scene aircraft endurance, time enroute search areas, division of search area among different search units, maximum rescue coverage intercepts, fixes from radio direction finder bearings, and many other calculations familiar to search planners could all be available instantly from a remote computer terminal.

The Coast Guard Amver computer center at Governor's Island New York regularly receives weather data by wire from Fleet Numerical Weather Central which is used to produce weather maps. The fields required for the Search Planning Program could also be transmitted to a central Coast Guard computer facility. Remote terminals connected to this facility and installed in Rescue Coordination Centers (RCC's) could provide the output from this program, Amver surface picture plots, and other useful data directly to search planners.

B. DETERMINATION OF SEARCH AREAS

It is recommended that the findings of parts IV and V of this thesis be evaluated by the Coast Guard and applicable portions be included in the National Search and Rescue Manual.

C. FUTURE RESEARCH

There are many unexplored areas in the field of Search Planning in which further research may yield valuable results.

1. The Trackline Search

Although the type of point-datum search presented in parts IV and V are computed in two dimensions, there are times when the target's distribution is centered on a line of position (or trackline), which presents a problem

essentially one dimensional in nature.



If a boat departs point A intending to follow a certain track AB to point B, and does not arrive at point B, and if no other information is available as to his probable position, a one-dimensional or trackline search problem is presented.

a. Partial Solution

Assuming that it is decided to begin the searching efforts by executing just one sweep along the length of the trackline, what is the probability that the target will be located? The following analysis is for the inverse cube law of detection.

Given the standard deviation of the target's error of position σ , and given sweep width, W , where

$$W = 2\sqrt{2\pi m} \quad (36)$$

Solving for m , which includes visibility and other factors,

$$m = \frac{W^2}{8\pi} \quad (37)$$

The probability of detecting a uniformly distributed target is

$$d(x) = 1 - e^{-\frac{2m}{x^2}} \quad (38)$$

$$= 1 - e^{-\frac{W^2}{4\pi x^2}} \quad (39)$$

Introducing a new variable, $\beta = \frac{2\sigma}{W}$

$$d(x) = 1 - e^{-\frac{\sigma^2}{\beta^2 \pi x^2}} \quad (40)$$

The probability that the target is located at some distance x from the trackline may be assumed to be

$$p(x) = \frac{1}{\sqrt{2\pi} \sigma} e^{-\frac{x^2}{2\sigma^2}} \quad (41)$$

Thus, the probability of detecting this target is

$$P = \int_{-\infty}^{+\infty} \left(1 - e^{-\frac{\sigma^2}{\beta^2 \pi x^2}}\right) \left(\frac{1}{\sqrt{2\pi} \sigma} e^{-\frac{x^2}{2\sigma^2}}\right) dx \quad (42)$$

$$= 1 - \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi} \sigma} e^{-\left(\frac{x^2}{2\sigma^2} + \frac{\sigma^2}{\beta^2 \pi x^2}\right)} dx \quad (43)$$

Introducing $\gamma = \frac{x}{\sqrt{2}} \sigma$, $d\gamma = \frac{1}{\sqrt{2}} \sigma dx$

$$P = 1 - \sqrt{2} \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi}} e^{-\left(\gamma^2 - \frac{1}{2\pi\beta^2 \gamma^2}\right)} d\gamma \quad (44)$$

which has the solution

$$P = 1 - e^{-\frac{\sqrt{2}}{\beta}} = 1 - e^{-\frac{W}{\sqrt{2}\sigma}} \quad (45)$$

b. General Solution

The solution for probability P of detecting a target on a trackline search for more than one sweep involves a more complicated expression, one which does not lend itself to such a simple solution. Since a trackline search is executed one sweep at a time, a general solution for the optimum distance of each sweep from the trackline is indicated, and should be the subject of further study.

2. Optimum Search Speed

The Search and Rescue Manual prescribes a "moderate" speed for searching. Koopman's formula for sweep width, from (9) gives

$$W = \sqrt{\frac{2kh}{\omega}}$$

This indicates that sweep width is inversely proportional to the square root of the relative speed of the target, w . When search speed is very large in comparison to target speed, w takes on the value of the searcher's speed. As w increases, however, the amount of search path length L that can be covered in a certain period of time increases proportionally:

$$L = K, \omega$$

It follows that the amount of search effort, $W \times L$, that can be effected by a certain number of aircraft in a fixed period of time increases as the square root of search speed:

$$\frac{W}{S} = K_2 = \frac{WL}{A}$$

$$A = \frac{WL}{K_2}$$

$$\frac{WL}{K_2} = A = \frac{\sqrt{\frac{2kh}{w}} K_1 w}{K_2} = \frac{K_1}{K_2} \sqrt{2khw} \quad (47)$$

It may be argued, then, that when time is a factor, such as where persons in distress may not survive for long periods of time, searching should be accomplished at the highest speed practicable. In addition, since the coverage of a designated search area will take less time at a higher speed, lookouts may encounter less fatigue, and the effectiveness of the search may be enhanced.

D. CONCLUSION

In conclusion, there is a need for more scientific research in the practical aspects of search planning, and a corresponding need for the education of search planners in the fields of probability and search theory.

APPENDIX A

USER'S GUIDE TO SEARCH PLANNING PROGRAM

1. Description

The MONTEREY SEARCH PLANNING PROGRAM is a computer program which solves open ocean drift plotting problems, and provides datum, minimax datum, Total Probable Error of Position, and Search Radius for both simple and complex searches. The use of this program is available upon request, on a test basis, to all Rescue Coordination Centers through the facilities of the U.S. Navy Fleet Numerical Weather Facility, Monterey, California.

2. Input Data

a. Leeway Code

For this program, leeway is expressed as a two-digit code as shown in Table 1.

Leeway Code

00	No Leeway
10	Liferaft with Drogue
11	Liferaft without Drogue
12	Liferaft (Minimax)
13 - 19	Downwind drift (minimax) Minimum = 1% of wind velocity Maximum = Second digit as % of Wind Velocity.
20,30,etc.	Downwind drift at 2%,3%, etc. of the wind velocity
21 - 99	Minimax drift at some fixed percent of wind velocity equal to first digit; Deflection to the right and left of the wind line equal to 10 degrees times the second digit.

Table 1. Leeway Code

Example: 43 = 4% of wind velocity

$\pm$ 30 degrees off wind line

b. Number of Starting Points

The number of starting (or distress) positions must be indicated. The maximum number that can be supplied is nine.

c. Number of Datum Times

The number of datum (or search) times for which plots are requested must be supplied. The maximum number of these is also nine.

d. Starting Point Data

Starting positions must be entered in chronological order and each point must be fully identified by:

(1) Date-time group (time zone Zulu)

(2) Month

(3) Latitude and Longitude in degrees and minutes.

Tenths of minutes must be specified. The number of these starting positions must agree with paragraph 2.a.

e. Datum Times

Complete Date-time group (including month) for each datum time must be supplied, in chronological order. The number of these datum times must agree with paragraph 2.c.

f. Last Known Position

This is the last known position of the search object (see Para. 611, National Search and Rescue Manual) to be

used in computing DR position error. This position must be complete with degrees, minutes, and tenths of minutes. If DR position error is not applicable, enter one of the initial positions from 2.d.

g. Error Factors

These factors must all be specified to at least one decimal place, in the following order:

(1) Probable navigation error of search craft.

(2) Initial probable error in position of the search object.

(3) Percent of DR distance to be applied as DR error (See Para. 611, National Search and Rescue Manual). Enter 0.0 if not applicable.

h. Search Designators

These should be one-digit numbers, from 0 to 5, which describe which Safety Factors are to be applied to the Total Probable Error of position for each datum time. One digit must be supplied for each datum time.

0 No search radius is to be computed for that datum time

1,2,3,4,5 The Safety Factor corresponding to search 1,2,3,4, or 5 is to be applied.

3. Message Request Format

A message request to Fleet Numerical Weather Central

will insure that the data is entered correctly into the computer:

FM CEA

TO FLENUMWEACEN MONTEREY

BT

UNCLAS

DISTRESS HOMEY 65 OVERDUE

1. REQUEST SAR PLOT.

2. DATA:

A. 12/2/3//

B. 030900Z AUG, 3520.0N, 05216.5W/031200Z AUG,
3600.0N, 05140.0W//

C. 031600Z AUG/032200Z AUG/040200Z AUG//

D. 3500.0N, 05140.0W/5.0/10.0/0.10/102//

This sample message requests a minimax plot of a liferaft from two initial positions, with data requested for three different times (para. 2.A.). The initial positions and date-time groups are given in para. 2.B. (note that 2 digits are used to express degrees latitude and 3 digits are used for degrees longitude).

Paragraph 2.C. gives the date-time groups of the datum times. Paragraph 2.D. gives the last known position, error factors, and search designators. for this example, the first search is to be computed for 031600Z and a second

search for 040200Z. No search radius is to be computed for 032200Z; positions and position errors will still be provided.

4. Caution: Offshore Regions

This program is designed primarily for open ocean search; when data is supplied for water areas within 100 miles from shore, answers should be checked by hand calculations. Requests for SAR Plots within 10 miles from shore should be avoided.

Weather information used in this program is applicable to the Northern Hemisphere only.

EXAMINATION OF CRITERIA FOR REPEATED SEARCHES

INVERSE CURVE LAW, PARALLEL SWEEPS FOR PROBABILITY OF DETECTION

LT J. H. DISCENZA, USCG

SEARCH NUMBER	OPTIMUM RADIUS	TRACK SPACING	PROBABILITY TARGET IN AREA	PROBABILITY OF DETECTION OF SUCCESS	STANDARD RADIUS	TRACK SPACING	PROBABILITY TARGET IN AREA	PROBABILITY OF DETECTION	PROBABILITY OF SUCCESS
SWEEP WIDTH SET TO 0.04 TIMES PROBABLE ERROR									
MILES FLOWN/PROBABLE ERROR=114.2, TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 4.8									
1	1.08	0.03	0.636	0.904	0.512	1.10	0.04	0.647	0.511
MILES FLOWN/PROBABLE ERROR=241.7, TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 10.2									
2	1.64	0.04	0.789	0.766	0.604	1.60	0.04	0.764	0.603
MILES FLOWN/PROBABLE ERROR=377.6, TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 16.0									
3	2.07	0.04	0.847	0.759	0.643	2.00	0.04	0.815	0.640
MILES FLOWN/PROBABLE ERROR=499.4, TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 21.2									
4	2.43	0.04	0.880	0.740	0.651	2.30	0.04	0.809	0.639
MILES FLOWN/PROBABLE ERROR=600.0, TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 25.0									
5	2.74	0.04	0.897	0.704	0.631	2.50	0.04	0.742	0.570

REDUCE EFFORT 50%

SEARCH NUMBER	OPTIMUM RADIUS	TRACK SPACING	PROBABILITY TARGET IN AREA	PROBABILITY OF DETECTION OF SUCCESS	STANDARD RADIUS	TRACK SPACING	PROBABILITY TARGET IN AREA	PROBABILITY OF DETECTION	PROBABILITY OF SUCCESS
MILES FLOWN/PROBABLE ERROR= 57.1, TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 2.4									
1	0.85	0.04	0.469	0.701	0.320	1.10	0.08	0.647	0.304
MILES FLOWN/PROBABLE ERROR=120.9, TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 5.1									
2	1.30	0.05	0.651	0.655	0.427	1.60	0.08	0.828	0.398
MILES FLOWN/PROBABLE ERROR=188.8, TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 8.0									
3	1.56	0.05	0.744	0.635	0.473	2.00	0.08	0.907	0.424
MILES FLOWN/PROBABLE ERROR=247.7, TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 10.6									
4	1.85	0.05	0.794	0.615	0.488	2.30	0.08	0.935	0.439
MILES FLOWN/PROBABLE ERROR=295.0, TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 12.5									
5	2.20	0.05	0.819	0.580	0.475	2.50	0.08	0.940	0.440

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MONTEREY SEARCH PLANNING PROGRAM
PROGRAMMER: LT J. H. DISCENZA, USCG
NAVAL POSTGRADUATE SCHOOL, MONTEREY, CALIFORNIA

PURPOSE: TO PROVIDE THE SEARCH AND RESCUE MISSION COORDINATOR
WITH A COMPUTER AID IN PLANNING AN OCEAN SEARCH.
REFERENCES:
(1) NATIONAL SEARCH AND RESCUE MANUAL, CG-308
(2) W.E. HUBERT, T. LAEVASTU, SYNOPTIC ANALYSIS AND
FORECASTING OF SURFACE CURRENTS, JUNE 1967
(3) W.H. RICHARDSON, EMPIRICAL SWEEP WIDTH ANALYSIS,
SCRIPPS INSTITUTION OF OCEANOGRAPHY, 1968

DISCUSSION:
THE BASIC PLANNING PROCESS IN THE PROGRAM IS ONE OF
AN OPEN OCEAN SEARCH FOR A DISTRESSED CRAFT WHERE SOME SOME
BEGINNING POINTS ARE KNOWN, AND WHERE A DATUM (OR DATUM POINT
TS) ARE REQUIRED FOR SOME FUTURE TIME. ALTHOUGH THE PROGRAM
IS SPECIFICALLY DESIGNED TO WORK WITH WEATHER DATA FROM A
TAPE OR DISK DATA BANK OF WEATHER INFORMATION, PROVISION IS
MADE FOR OPERATOR ENTRY OF WEATHER INFORMATION IF SUCH DATA
BANK OF WEATHER IS NOT AVAILABLE.
ENTERING ARGUMENTS:
IX: CLASS NUMBER OF SEARCH OBJECT - RELATES TO SIZE
DESC: AND DRIFTING CHARACTERISTICS
ML: ALPHAMERIC DESCRIPTION OF SEARCH OBJECT
OF DATUM
AL: THE DATES AND TIMES OF THE STARTING POSITIONS
LAD, YLA, D: LATITUDE OF STARTING POSITIONS
LCD, YLO, H: LONGITUDE OF STARTING POSITIONS
M2: NUMBER OF TIMES DATUM IS TO BE COMPUTED
T2: TIMES FOR WHICH DATUM IS TO BE COMPUTED

OUTPUTS:
LAF, FLA, DE: LATITUDE OF DATUM POINTS
LCF, FLO, HE: LONGITUDE OF DATUM POINTS
WRITE(6,100)
1001,FORMAT(1 MONTEREY SEARCH PLANNING PROGRAM'//, ENTERING ARGUMENTS
,TS'//, CLASS',2I2)

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100  FORMAT(' MCINTEREY SEARCH PLANNING PROGRAM')
COMMON LAD(9), YLA(9), D(9), LOD(9), YLO(9), H(9), M1, CHECK, O,
1DESC(15), HE(9), T2, T3, A1, T2(9), MON(9), IX1, IX2, TAP,
2CD1, CD2, P, FLO(9, 18), FLO(9, 18), LAF, LDF, M2, M4, M6, CV1, CV2, CV3, CV4,
3CD1, CD2, P, FLO(9, 18), FLO(9, 18), LAF, LDF, M2, M4, M6, CV1, CV2, CV3, CV4,
INTEGER AI(3, 9), T2(3, 9), T3(3, 9), C(9, 18), WIND(2, 9, 9)
INTEGER LAF(9, 9), LOF(9, 9)
TAP=0
P=3.14159/180.
WRITE(6, 101)
FORMAT(' ENTER LEEWAY CODE, 1 BLANK, THEN DESCRIPTION')
200  READ(5, 200) IX1, IX2, LEVEL, DESC
FORMAT(2I1, 1I, 15A4)
CO 11 I=1, 9
11  O(I)=0
IF(LEVEL.EQ.0) GO TO 16
IF(LEVEL.EQ.5) GO TO 17
IF(LEVEL.EQ.5) GO TO 18
IF(LEVEL.EQ.4) GO TO 20
DO 12 I=1, LEVEL
12  O(I)=1
18  DO 19 I=1, 9
19  O(I)=1
20  DO 21 I=1, 9
21  O(I)=1
17  DO 22 I=1, 3
22  O(I)=1
16  O(LEVEL-3)=1
CONTINUE
IF(O(I).EQ.1) WRITE(8, 1001) IX1, IX2
IF(O(I).EQ.1) WRITE(8, 1011) DESC
1011 FORMAT(103)
WRITE(6, 103)
103  FORMAT(202) M1, DUM1, DUMJ
PEAD(5, 11, 2F4.0)
202  FORMAT(11, 2F4.0)
IF(O(I).EQ.1) WRITE(8, 1002) M1
1002  FORMAT(1, 0) M4=2*M1
IF(IX2.GT.0)
CD1=+IX2*10
CD2=-IX2*10
CV1=FLOAT(IX1)/25.
CV2=FLOAT(IX1)/25.

```

SAR00C490
SAR000500
SAR000510
SAR000520
SAR000530
SAR000540
SAR000550
SAR000560
SAR000570
SAR000580
SAR000590
SAR000600
SAR000610
SAR000620
SAR000630
SAR000640
SAR000650
SAR000660
SAR000670
SAR000680
SAR000690
SAR000700
SAR000710
SAR000720
SAR000730
SAR000740
SAR000750
SAR000760
SAR000770
SAR000780
SAR000790
SAR000800
SAR000810
SAR000820
SAR000830
SAR000840
SAR000850
SAR000860
SAR000870
SAR000880
SAR000890
SAR000900
SAR000910
SAR000920
SAR000930
SAR000940
SAR000950
SAR000960

```

CV3=0.
CV4=0.
IF(IX1.NE.1)GO TO 10
CD1=0.
CD2=0.
IF(IX2.GT.2)GO TO 2
CV1=.098
CV2=.226
CV3=0.
CV4=0.
IF(IX2.LT.2)M4=M1
IF(IX2.EQ.1)CV1=CV2
IF(IX2.EQ.1)CV3=CV4
GO TO 10
CV2=FLOAT(IX2)/100.
CONTINUE
IF(O(1).EQ.1)WRITE(8,1003)M4
1003 FORMAT(' NUMBER OF SEPARATE TRACKS TO BE PLOTTED,M4=', I2)
1015 FORMAT(' DIVERGENCE OF TRACKS=+',F4.1,' AND',F5.1)
1016 IF(O(2).EQ.1)WRITE(8,1015)CD1,CD2
IF(O(2).EQ.1)LEENAY=,F7.4,+,F7.4,,'X WIND')
IF(O(2).EQ.1)WRITE(8,1016)CV3,CV1
IF(O(2).EQ.1)WRITE(8,1016)CV4,CV2
33 WRITE(6,106)
106 FORMAT(' LIST CHRONOLOGICALLY: STARTING TIMES AND POSITIONS, EX:')
107 READ(5,203)((A1(I,J),I=1,3),TZ(J),MCN(J),LAD(J),YLA(J),D(J),LOD(J)
1,YLO(J),H(J),J=1,M1)
1010 IF(O(1).EQ.1)WRITE(8,1010)
FORMAT(' STARTING TIMES AND POSITIONS ENTERED:')
DO 40 J=1,M1
40 A1(1,J)=JULIAN(MON(J),A1(1,J))
IF(O(1).EQ.1)WRITE(8,1017)
IF(O(1).EQ.1)WRITE(8,1023)((A1(I,J),I=1,3),LAD(J),YLA(J),D(J),LOD(
1,J),YLO(J),H(J),J=1,M1)
1023 YLO(J),YLO(J),H(J),J=1,M1)
1017 FFORMAT(3)2,Y12,,'-',F5.2,A1)
203 FFORMAT(3)2,DATE-TIME LATITUDE
CALL NSEW
IF(O(2).EQ.1)WRITE(8,1004)CHECK
1004 FFORMAT(' ANSWER TO CHECK: ',A1)
DATA WRONG/1HN/
IF(CHECK.EQ.1)GO TO 33
WRITE(6,108)
108 FFORMAT(' ENTER NUMBER OF TIMES DATUM IS TO BE COMPUTED NOW:')
204 READ(5,204)M2,TAP
FORMAT(2)1)

```

SARC0970
SARC0980
SARC0990
SARC1000
SARC1010
SARC1020
SARC1030
SARC1040
SARC1050
SARC1060
SARC1070
SARC1080
SARC1090
SARC1100
SARC1110
SARC1120
SARC1130
SARC1140
SARC1150
SARC1160
SARC1170
SARC1180
SARC1190
SARC1200
SARC1210
SARC1220
SARC1230
SARC1240
SARC1250
SARC1260
SARC1270
SARC1280
SARC1290
SARC1300
SARC1310
SARC1320
SARC1330
SARC1340
SARC1350
SARC1360
SARC1370
SARC1380
SARC1390
SARC1400
SARC1410
SARC1420
SARC1430
SARC1440

```

1005 IF (O(1).EQ.1)WRITE(8,1005)M2
1006 FORMAT(: DATUM TO BE COMPUTED ',I1,' TIMES.')
```

```

1009 WRITE(6,109)
1010 FORMAT(6,109)
1011 READ(5,205)((T2(I,J),I=1,3),MON(J),J=1,M2)
1012 FORMAT(9(3I2,1X,A3,1X))
1013 IF (O(1).EQ.1)WRITE(8,1006)((T2(I,J),I=1,3),J=1,M2)
1014 DO 41 J=1,M2
1015 T2(1,J)=JULIAN(MON(J),T2(1,J))
1016 FORMAT(: THESE TIMES ARE ',9(3I2,1H,))
1017 CALL WXCMP
1018 CALL DATUM
1019 CALL RADII
1020 DO 61 J=1,M2
1021 IF (M4.EQ.M1)GO TO 62
1022 WRITE(6,133)
1023 FORMAT(: THE FOLLOWING ARE THE MINIMAX DATUM POINTS FOR THE')
```

```

133 GO TO 63
134 WRITE(6,130)
135 FORMAT(: THE FOLLOWING ARE THE DATUM POINTS FOR THE')
```

```

136 WRITE(6,131)T2(2,J),T2(3,J)
137 FORMAT(13,1H:,13) SEARCH(:)
138 WRITE(6,132)((LAF(J,I),FLA(J,I),DE(J,I),LOF(J,I),FLO(J,I),HE(J,I),
139 IC(J,I),RADIUS(J,I),WIND(MM,I),MM=1,2),I=1,M1)
140 IC(J,I),RADIUS(J,I),F4.1,A1.4X),POS. ERROR:',F6.1', RADIUS:',F6.1',
141 ILES:',/10X', WIND:',F5.1',KTS FROM:',F5.0)
142 IF (RADIUS(J,I).EQ.0.)GO TO 61
143 WRITE(6,134)
144 READ(5,135)ANS
145 IF (ANS.EQ.WRONG)GO TO 61
146 WRITE(6,136)
147 READ(5,137)ALT
148 WRITE(6,138)
149 READ(5,137)VIS
150 WRITE(6,139)
151 READ(5,137)VLEN
152 WRITE(6,140)
153 READ(5,137)CLOUDS
154 WW=SWIDTH(VLEN,VIS,ALT,WIND(1,I,J),CLOUDS)
155 WRITE(6,141)WW
156 FORMAT(: SWEEP WIDTH? Y OR N')
```

```

134 FORMAT(A1)
135 FORMAT(: ENTER SEARCH ALTITUDE (EX:800.))
136 FORMAT(: ENTER SEARCH ALTITUDE (EX:800.))
137 FORMAT(: ENTER SEARCH ALTITUDE (EX:800.))
138 FORMAT(: ENTER SEARCH ALTITUDE (EX:800.))
139 FORMAT(: ENTER SEARCH ALTITUDE (EX:800.))
140 FORMAT(: ENTER SEARCH ALTITUDE (EX:800.))
141 FORMAT(: ENTER SEARCH ALTITUDE (EX:800.))
```

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142 VISIBILITY IN MILES (EX:10.0)')
143 BOAT LENGTH IN FEET (EX:36.0)')
144 CLOUD COVER IN FRACTION (EX: 0.9)')
145 WIDTH=',F10.1', MILES.')
```

```

61  CONTINUE
    WRITE(6,999)
    WRITE(6,998)DESC
999  FORMAT(' GOOD LUCK ON YOUR SEARCH LET ME KNOW IF YOU FIND')
998  STOP
    END
-----
SUBROUTINE NSEW
PROGRAMMER: LT J. H. DISCENZA, USCG

THIS SUBROUTINE CONVERTS LATITUDE AND LONGITUDE AS
EXPRESSED IN "NORTH" AND "SOUTH" TO ALGEBRAIC (+ OR -)
QUANTITIES. IN ADDITION IT READS THE ALGEBRAIC QUANTITIES
BACK TO THE OPERATOR FOR HIM TO DOUBLE CHECK.

ENTERING ARGUMENTS:
LAD,YLA,D:  LATITUDES (D=N,S)
LCD,YLO,H:  LONGITUDES (H=E,W)
MI:         THE NUMBER OF POSITIONS TO BE CONVERTED

OUTPUTS:
LAD,YLA:    ALGEBRAIC VERSION OF LATITUDE
LCD,YLO:    ALGEBRAIC VERSION OF LONGITUDE
CHECK:      A "Y" OR "N" ANSWER FROM THE OPERATOR WHICH
            INDICATES WHETHER THE LIST OF LATITUDES AND
            LONGITUDES PRODUCED ARE CORRECT.

```

```

SUBROUTINE NSEW
COMMON LAD(9),YLA(9),D(9),LCD(9),YLO(9),H(9),MI,CHECK,D,
1DESC(9),HE(9),F(9),T2,T3,A1,TZ(9),MON(9),IX1,IX2,TAP,
2DESC(15),F(15),FLO(9,18),LAF,LOF,M2,M4,M6,CV1,CV2,CV3,CV4,
3CDD1,CDD2,P,DD(9,18),RADIUS(9,9),C(9,18),WIND(2,9,9)
INTEGER AL(3,9)
INTEGER LAF(9,9),LOF(9,9)
DATA XS,XE/1HS,1HE/
DO 4 I=1,MI
13  IF(D(I).EQ.XS) GO TO 14
    GO TO 25
14  LAD(I)=-LAD(I)

```

```

25 YLA(I)=-YLA(I)
   IF(H(I).EQ.XE)GO TO 35
   GO TO 44
35 LOD(I)=-LOD(I)
   YLO(I)=-YLO(I)
44 WRITE(6,800)LAD(I),YLA(I),LOD(I),YLO(I),D(I),H(I)
800 FORMAT(16,F10.1,I6,F10.1,' CHECK:',2A4)
801 WRITE(6,801)
801 FORMAT(' CHECK. TYPE Y OR N')
802 READ(5,802)CHECK
802 FORMAT(A1)
END
-----C-----
SUBROUTINE WXCOMP
PROGRAMMER: LT J. H. DISCENZA, USCG

THIS SUBROUTINE HANDLES DATA FROM A WEATHER TAPE, AND
COMPUTES SET, DRIFT, AND DRIFT ERROR FOR SEVERAL TRACKS AT
A TIME. THE WEATHER DATA IS STORED ON TAPE IN "FIELDS".
THESE FIELDS CONTAIN ALL DATA FOR ONE PARAMETER (WIND,
CURRENT) FOR THE NORTHERN HEMISPHERE FOR ONE OBSERVATION
TIME. THE REFERENCE SYSTEM FOR THE WEATHER DATA IS A
SQUARE GRID, 63 POINTS ON A SIDE, BASED ON A POLAR STEREO-
GRAPHIC PROJECTION. THE POINT 32,32 IS ON THE NORTH POLE.
ALL OTHER POINTS MAY BE DETERMINED FROM LATITUDE AND
LONGITUDE BY THE FOLLOWING FORMULAE:
RI=32+ 31.205((1-SIN LAT)/(1+SIN LAT))1/2 X COS(LONG+10°)
RJ=32- 31.205((1-SIN LAT)/(1+SIN LAT))1/2 X SIN(LONG+10°)

THE PROGRAM BEGINS BY USING THESE FORMULAE TO CONVERT
STARTING POSITIONS TO THIS GRID SYSTEM. THEN IT TESTS
ALL COORDINATES FOR EXTREMES AND SELECTS A SET OF WEATHER
OBSERVATION POSITIONS LARGE ENOUGH TO PROVIDE SUFFICIENT
WEATHER DATA FOR THE PROBLEM.
IT THEN SEARCHES THE DATA BANK FOR THE PROPER TIME
INTERVAL AND BEGINS READING IN WEATHER. THE COMPUTATIONS
BEGIN AT THE TIME OF THE EARLIEST APPROPRIATE WEATHER (T)
OBSERVATION AND ADVANCES HOUR BY HOUR. AT EACH TIME (T)
THE WEATHER AT THE PREVIOUS OBSERVATION (A3) AND THE WEATHER
AT THE NEXT OBSERVATION (A5) ARE USED.

```



```

C          SFC=.01944/16.
C          IF(O(1).EQ.1)WRITE(8,1137)SFW,SFC
C
C          CCNVERT LATITUDE AND LONGITUDE OF STARTING POSITIONS
C          TO FLEET NUMERICAL WEATHER FACILITY GRID SYSTEM
C
C          K=0
C          DO 161 J=1,M1
C          CALL FNIO(LAD(J),YLA(J),LOD(J),YLO(J),RI(J),RJ(J),FM(J),K)
C          IF(O(1).EQ.1)WRITE(8,1110)(RI(J),RJ(J),J=1,M1)
C
C          ITS=A1(1,1)
C          ITT=A1(2,1)-12
C          IF(ITT)226,162,162
C          ITT=ITT+24
C          ITS=ITS-1
C          IF(O(1).EQ.1)WRITE(8,1119)ITS,ITT
C
C          READ FIELD FOR NEXT TIME INTERVAL
C          IF(TAP.EQ.0)READ(12,ERR=2000)ITITLE,W2
C          M12=M12+1
C          IF(O(1).EQ.1)WRITE(8,1111)
C          IF(O(1).EQ.1)WRITE(8,1112)ITITLE
C          W1(1)=M12/8
C          M13=M12/4
C          W1(2)=12*(M13-2*(M13/2))
C          W1(3)=00
C          IF(O(1).EQ.1)WRITE(8,1115)W1
C          IF(O(5).EQ.1)WRITE(8,1113)
C          IF(O(5).EQ.1)WRITE(8,1114)(W2(1,J),J=1,4)
C
C          TEST INITIALIZE SWITCH 'IWIN'
C          IF(IWIN.EQ.1)GO TO 225
C
C          IF INITIALIZE SWITCH FALSE, COMPARE TIME OF WEATHER
C          OBSERVATION TO TIME OF EARLIEST STARTING POINT
C          IF(W1(1)-ITS)162,223,224
C          IF(W1(2)-ITT)162,224,224
C          WRITE(6,1105)
C          GO TO 2000
C
C          IF WEATHER IS WITHIN REQUIRED TIME FRAME START DRIFT
C          COMPUTATIONS. SET INITIALIZE SWITCH TO TRUE.
C          DO 401 I=1,3
C          T3(I)=W1(I)
C          IF(O(1).EQ.1)WRITE(8,1116)W1
C
C          SEARCH STARTING POSITIONS FOR EXTREMES
C          225 TEMPI=RI(1)

```

SAR033290
 SAR033300
 SAR033310
 SAR033320
 SAR033330
 SAR033340
 SAR033350
 SAR033360
 SAR033370
 SAR033380
 SAR033390
 SAR033400
 SAR033410
 SAR033420
 SAR033430
 SAR033440
 SAR033450
 SAR033460
 SAR033470
 SAR033480
 SAR033490
 SAR033500
 SAR033510
 SAR033520
 SAR033530
 SAR033540
 SAR033550
 SAR033560
 SAR033570
 SAR033580
 SAR033590
 SAR033600
 SAR033610
 SAR033620
 SAR033630
 SAR033640
 SAR033650
 SAR033660
 SAR033670
 SAR033680
 SAR033690
 SAR033700
 SAR033710
 SAR033720
 SAR033730
 SAR033740
 SAR033750
 SAR033760

4

```

TEMP2=RI(1)
TEMP3=RJ(1)
TEMP4=RJ(1)
DO 166 I=1,M1
  IF(RI(I).GT.TEMP1)TEMP1=RI(I)
  IF(RI(I).LT.TEMP2)TEMP2=RI(I)
  IF(RJ(I).GT.TEMP3)TEMP3=RJ(I)
  IF(RJ(I).LT.TEMP4)TEMP4=RJ(I)
166
C
C      SELECT MAXIMUM GRID POINTS 3 MESH LENGTHS OUTSIDE.
      IC1=TEMP1+3.
      IC2=TEMP2-3.
      IC3=TEMP3+3.
      IC4=TEMP4-3.
C
C      DETERMINE SIZE OF WEATHER MATRIX TO BE SELECTED
      N8=IC1-IC2
      M8=IC3-IC4
      IF(O(2).EQ.1)WRITE(8,1118)IC3,M8,IC2,IC1,N8,IC4
      TEST FOR MINIMAX
      IF(M4.EQ.M1)GO TO 263
C
C      IF MINIMAX, EXPAND SET OF STARTING POSITIONS TO DOUBLE
      ORIGINAL SIZE TO ACCOMMODATE TWO TRACKS FOR EACH STARTING
      POINT
      DO 209 J=1,M1
        K=M1+J
        RI(K)=RI(J)
        RJ(K)=RJ(J)
      DO 210 I=1,M1
        K=M1+I
        J=2*I
        RI(J)=RI(K)
        RJ(J)=RJ(K)
        RI(J-1)=RI(K)
        RJ(J-1)=RJ(K)
        IF(O(4).EQ.1)WRITE(8,1133)(RI(L),RJ(L),L=1,M4)
210      CONTINUE
263
C
C      SELECT APPROPRIATE WEATHER AND STORE IN A3
      DO 169 M=1,4
        IF(IWIN.EQ.0.AND.M.EQ.1)GO TO 168
        IF(TAP.EQ.0)READ(12,ERR=2000)TITLE,W2
        M12=M12+1
        W1(1)=M12/8
        M13=M12/4
        W1(2)=12*(M13-2*(M13/2))

```


172	T(I)=T3(I)			SAR04730
	IF(O(3).EQ.1)WRITE(R,1117)TA,T			SAR04740
171	CONTINUE			SAR04750
	DO 170 J=1,M1			SAR04760
	IF(O(2).EQ.1)WRITE(8,1101)			SAR04770
	IF(O(2).EQ.1)WRITE(8,1102)J			SAR04780
	TEST STARTING POINT INITIALIZE SWITCH TO SEE IF THE			SAR04790
	TRACK(S) FOR EACH STARTING POINT HAVE BEGUN DRIFTING.			SAR04800
	IF(ITIN(J).EQ.1)GO TO 175			SAR04810
				SAR04820
				SAR04830
				SAR04840
	IF NOT BEGUN, TEST STARTING DATES AND TIMES.			SAR04850
	IF(O(2).EQ.1)WRITE(8,1103)T(1),A1(1,J)			SAR04860
	IF(T(1)-A1(1,J))170,173,174			SAR04870
173	IF(O(2).EQ.1)WRITE(8,1104)T(2),A1(2,J)			SAR04880
	IF(T(2)-A1(2,J))170,176,174			SAR04890
176	IF(O(2).EQ.1)WRITE(8,1106)			SAR04900
	IF(T(3)-A1(3,J))177,178,179			SAR04910
				SAR04920
	SET VALUE OF R, THE PORTION OF THE FIRST HOUR DRIFTING.		10,11,12	SAR04930
177	R=FLOAT(A1(3,J)-T(3))/60.			SAR04940
	GO TO 180			SAR04950
178	R=1.			SAR04960
	GO TO 180			SAR04970
179	WRITE(6,1107)			SAR04980
	R=1.+FLOAT(T(3)-A1(3,J))/60.			SAR04990
	GO TO 180			SAR05000
175	IF(O(2).EQ.1)WRITE(8,1108)			SAR05010
				SAR05020
	TEST DATUM TIME TERMINATION SWITCH. IF TRUE, TEST NEXT			SAR05030
	DATUM TIME.			SAR05040
	DO 181 II=1,M2		13 - 16	SAR05050
	IF(ITTERM(II).EQ.0)GO TO 180			SAR05060
181	CONTINUE			SAR05070
	WRITE(6,1105)			SAR05080
180	K=II			SAR05090
	IF(O(2).EQ.1)WRITE(8,1109)K			SAR05100
	IF(O(2).EQ.1)WRITE(8,1103)T(1),T2(1,K)			SAR05110
	IF(T(1)-T2(1,K))182,183,174			SAR05120
183	IF(O(2).EQ.1)WRITE(8,1104)T(2),T2(2,K)			SAR05130
	IF(T(2)-T2(2,K))182,184,174			SAR05140
174	WRITE(6,1105)			SAR05150
	GO TO 200			SAR05160
				SAR05170
	SET VALUE OF R, THE PORTION OF AN HOUR THIS PARTICULAR		17	SAR05180
	TRACK IS TO DRIFT.			SAR05190
182	R=1.			SAR05200

```

184 GO TO 180
    IF(Q(2).EQ.1)WRITE(8,1106)
    IF(T(3)-T2(3,K))185,186,187
C
C
C
    SET VALUE OF S, THE PORTION OF AN HOUR DRIFTED TOWARD 18,19,20
    A PARTICULAR DATUM TIME.
185 S=FLCAT(T2(3,K)-T(3))/60.
    GO TO 188
186 S=0.
    GO TO 188
187 WRITE(6,11107)
    S=FLOAT(T2(3,K)-T(3))/60.
C
C
    SET DATUM TIME TERMINATION SWITCH TRUE.
188 ITTERM(K)=1
    IF(K.NE.M2.OR.J.NE.M1)GO TO 180
    TERM=1.
C
C
    INTERPOLATE WIND AND CURRENT FOR THIS POSITION.
180 IM=M4/M1
    L=J*IM-IM+1
    JT1=FIX(RJ(L))-IC2
    JT1=FIX(RJ(L))-IC4
    QI=RJ(L)-FLCAT(JT1+IC2)
    QJ=RJ(L)-FLCAT(JT1+IC4)
    IF(Q(1).EQ.1)WRITE(8,1140)QI,QJ
    IT2=IT1+1
    JT2=JT1+1
    WV=A3(IT1,1,JT1,3)+QJ*(A3(IT1,JT2,3)-A3(IT1,JT1,3))
    WV=A3(IT1,1,JT1,4)+QJ*(A3(IT1,JT2,4)-A3(IT1,JT1,4))
    XU=A3(IT2,1,JT1,3)+QJ*(A3(IT2,JT2,3)-A3(IT2,JT1,3))
    XV=A3(IT2,1,JT1,4)+QJ*(A3(IT2,JT2,4)-A3(IT2,JT1,4))
    WI=WU+QI*(XU-WU)
    WJ=WV+QI*(XV-WV)
    CU=A3(IT1,1,JT1,1)+QJ*(A3(IT1,JT2,1)-A3(IT1,JT1,1))
    CV=A3(IT1,1,JT1,2)+QJ*(A3(IT1,JT2,2)-A3(IT1,JT1,2))
    DU=A3(IT2,1,JT1,1)+QJ*(A3(IT2,JT2,1)-A3(IT2,JT1,1))
    DV=A3(IT2,1,JT1,2)+QJ*(A3(IT2,JT2,2)-A3(IT2,JT1,2))
    CI=CU+QI*(DU-CU)
    CJ=CV+QI*(DV-CV)
    WU=A5(IT1,1,JT1,3)+QJ*(A5(IT1,JT2,3)-A5(IT1,JT1,3))
    WV=A5(IT1,1,JT1,4)+QJ*(A5(IT1,JT2,4)-A5(IT1,JT1,4))
    XU=A5(IT2,1,JT1,3)+QJ*(A5(IT2,JT2,3)-A5(IT2,JT1,3))
    XV=A5(IT2,1,JT1,4)+QJ*(A5(IT2,JT2,4)-A5(IT2,JT1,4))
    WU=WU+QI*(XU-WU)
    WV=WV+QI*(XV-WV)
    CU=A5(IT1,1,JT1,1)+QJ*(A5(IT1,JT2,1)-A5(IT1,JT1,1))
    CV=A5(IT1,1,JT1,2)+QJ*(A5(IT1,JT2,2)-A5(IT1,JT1,2))

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SAR05210
 SAR05220
 SAR05230
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 SAR05680

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C
C
DU=A5(IT2,JT1,1)+QJ*(A5(IT2,JT2,1)-A5(IT2,JT1,1))
DV=A5(IT2,JT1,2)+QJ*(A5(IT2,JT2,2)-A5(IT2,JT1,2))
CU=CU+QI*(DU-CU)
CV=CV+QI*(DV-CV)

C
C
      INTERPOLATE WEATHER DATA AS TO TIME
HRR=FLOAT(T(2)-T3(2))/12.
IF(O(4).EQ.1)WRITE(8,1139)WU,WV,CU,CV,WI,WJ,CI,CJ
IF(T(1).EQ.T3(1))GO TO 204
HRR=HRR+2.
204 WU=(WI+HRR*(WU-WI))*SFW
WV=(WJ+HRR*(WV-WJ))*SFW
CU=(CI+HRR*(CU-CI))*SFC
CV=(CJ+HRR*(CV-CJ))*SFC
IF(O(4).EQ.1)WRITE(8,1139)WU,WV,CU,CV

C
C
      SURVIVOR CRAFT LEEWAY FACTORS.
WV=ABS(WV)
IF(WV.LT.1.)GO TO 207
ANG=ATAN(WU/WV)
ANG=ANG/P
GO TO 208
207 ANG=0.
208 WV=SQRT(WU*WU+WV*WV)
WVWV=SQRT(WVWV)
IF(WV.LT.0)ANG=ANG-180.
NN=J*IM-IM+1
IF(L.NE.NN)GO TO 205
C-----WIND DRIFT FACTORS-----
WIND(1,J,K)=WV
WIND(2,J,K)=ANG+180.
WVWV=WVWV*(CV1+CV3*WVWV)
ANG=ANG+CD1
C-----
GO TO 206
C-----
205 WVWV=WVWV*(CV2+CV4*WVWV)
WIND(1,J,K)={WIND(1,J,K)+WVWV}/2.
WIND(2,J,K)={WIND(2,J,K)+ANG+180.}/2.
ANG=ANG+CD2
C-----
206 WV=WVWV*SIN(ANG)
WU=WVWV*COS(ANG)
IF(ITTERM(K).NE.1)GO TO 220
C
C
      CALCULATE U AND V COMPONENTS IN MILES, FOR S HOURS.
X=S*(WU+CU)
Y=S*(WV+CV)

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SAR05690
 SAR05700
 SAR05710
 SAR05720
 SAR05730
 SAR05740
 SAR05750
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 SAR06090
 SAR06100
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 SAR06140
 SAR06150
 SAR06160

```

C      INCREMENT DRIFT ERROR
C      DD(K,L)=DER(L)+SQRT(X*X+Y*Y)/8.
C
C      ADVANCE POSITIONS TO DATUM TIME IN FNWF COORDINATE SYSTEM
C      PI(L)=RI(L)+X/FM(J)
C      PJ(L)=RJ(L)+Y/FM(J)
C      IF(O(1).EQ.1)WRITE(8,1134)L,FM(J),X,Y,PI(L),PJ(L)
C
C      CCNVERT FROM GRID SYSTEM TO GEOGRAPHIC COORDINATES.
C      MNO=1
C      CALL FNIO(LAF(K,L),FLA(K,L),LOF(K,L),FLO(K,L),PI(L),PJ(L),FM(J),MN
C      10)
C      IF(O(1).EQ.1)WRITE(8,1136)XLAT,XLON,LAF(K,L),FLA(K,L),LOF(K,L),FLO
C      1(K,L)
C      WRITE(6,1120)K,L,LAF(K,L),FLA(K,L),LOF(K,L),FLO(K,L)
C
C      TEST TERMINATE SWITCH. IF FALSE, ADVANCE ALL TRACKS
C      ONE HOUR
C      NN=J*IM
C      IF(J.NE.M1.AND.L.EQ.NN)ITTERM(K)=0
C      IF(ITERM.NE.1)GO TO 220
C      IF(M4.EQ.M1)GO TO 230
C      IF(L.EQ.NN)GO TO 230
C      GO TO 240
C      220 X=R*(WU+CU)
C      Y=R*(WV+CV)
C
C      INCREMENT DRIFT ERROR
C      DER(L)=DER(L)+SQRT(X*X+Y*Y)/8.
C
C      ADVANCE POSITIONS R HOURS IN FNWF COORDINATE SYSTEM.
C      RI(L)=RI(L)+X/FM(J)
C      RJ(L)=RJ(L)+Y/FM(J)
C      IF(O(1).EQ.1)WRITE(8,1135)L,FM(J),X,Y,RI(L),RJ(L)
C      IF(M4.EQ.M1)GO TO 250
C      NN=J*IM
C      IF(L.EQ.NN)GO TO 250
C      L=J*IM
C      GO TO 228
C      240
C      250 ITIN(J)=1
C      170 CONTINUE
C
C      INCREMENT TIME ONE HOUR.
C      T(2)=T(2)+1
C      IF(T(2).LT.24)GO TO 251
C      T(2)=T(2)-24
C      T(1)=T(1)+1

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SAR061170
 SAR061180
 SAR061190
 SAR062000
 SAR062100
 SAR062200
 SAR062300
 SAR062400
 SAR062500
 SAR062600
 SAR062700
 SAR062800
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 SAR063000
 SAR063100
 SAR063200
 SAR063300
 SAR063400
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 SAR063600
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 SAR066000
 SAR066100
 SAR066200
 SAR066300
 SAR066400

251 IF(T(2).EQ.TA(2))GO TO 165

230 GO TO 171

2000 CONTINUE

11001 FORMAT(, BEGIN LOOP,)

11002 FORMAT(, STARTING POINT, I3)

11003 FORMAT(7X, TEST DATE, 7X, WX DATE, I5, START DATE, I5)

11004 FORMAT(7X, TEST HOUR, WX HOUR, I6, START HOUR, I6)

11005 FORMAT(, ***ERROR PROGRAM TERMINATING,)

11006 FORMAT(7X, TEST MINUTES,)

11007 FORMAT(, **WARNING** RESULTS MAY BE ERRONEOUS,)

11008 FORMAT(7X, TRACKS HAVE STARTED. CHECKING DATUM TIMES,)

11009 FORMAT(, SEARCH, I2, NEXT,)

11010 FORMAT(, RI, F10.5, RJ, F10.5)

1262 FORMAT(20I4)

1263 FORMAT(15A4)

1264 FORMAT(6X, Q, 11X, A, 11X, TLOT, 8X, S, 11X, C, /5F12.5)

11111 FORMAT(, WEATHER DATA FIELD TITLES: //, HRS FCTS HOUR DATE

11112 U/V PARAMETER,)

11113 FORMAT(, OSAMPLE FROM WEATHER FIELD:)

11114 FORMAT(, 12A8)

11115 FORMAT(, 4I20)

11116 FORMAT(, WEATHER READ FOR DATE-TIME: I3I6)

11117 FORMAT(12X, T3 DATE-TIME SET: I3I6)

11118 FORMAT(15X, TA DATE-TIME: I3I6 // 20X, T DATE-TIME SET: I3I6)

11119 FORMAT(, MAXIMUM GRID POINTS: I10/I21/I10, I12, I10/I22)

11120 FORMAT(, ACCEPT ANY WX OBS AFTER, 2I6)

11121 FORMAT(, SEARCH, I2, TRACK, I3, DATUM: I2(I6, F6.2))

11122 FORMAT(, OEXPAND STARTING POINTS TO ACCOMMODATE MINIMAX, //

114X, I, 19X, J, // (2F20.5))

1134 FORMAT(, SEARCH TRACK, I2, F20.10, 2F10.5, 2F20.10)

1135 FORMAT(8X, SEARCH TRACK, I2, F20.10, 2F10.5, 2F20.10)

1136 FORMAT(, SEARCH GEODGR: I2, F20.10, 2(I7, F7.2))

1137 FORMAT(, SCALE FACTOR = WIND: I2, F20.10, CURR: F20.10)

1138 FORMAT(, WEATHER MATRIX RETAINED: // (2I5, 4F30.1))

1139 FORMAT(, WIND, U, V: I2, F15.5, CURRENT, U, V: I2, F15.5)

1140 FORMAT(10X, QI: F15.5, QJ: F15.5)

RETURN

SAR0665C
SAR0666C
SAR0667C
SAR0668C
SAR0669C
SAR0670C
SAR0671C
SAR0672C
SAR0673C
SAR0674C
SAR0675C
SAR0676C
SAR0677C
SAR0678C
SAR0679C
SAR0680C
SAR0681C
SAR0682C
SAR0683C
SAR0684C
SAR0685C
SAR0686C
SAR0687C
SAR0688C
SAR0689C
SAR0690C
SAR0691C
SAR0692C
SAR0693C
SAR0694C
SAR0695C
SAR0696C
SAR0697C
SAR0698C
SAR0699C
SAR0700C
SAR0701C
SAR0702C
SAR0703C

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C
SUBROUTINE DATUM
  PROGRAMMER: LT J. H. DISCENZA, USCG
  COMMON LAD(9), YLA(9), D(9), LOD(9), YLO(9), H(9), M1, CHECK, O,
1061 1DE(9,9), HE(9,9), T2, T3, A1, Tz(9), MCN(9), IX1, IX2, TAP,
2061 2DE(9,9), FLA(9,9), FLO(9,9), LAF, LOF, M2, M4, M6, CV1, CV2, CV3, CV4,
3061 3CD1, CD2, P, DD(9,9), RADIUS(9,9), C(9,9), WIND(2,9,9)
  INTEGER A1(3,9), T2(3,9), T3(3,9), O(9)
  INTEGER LAF(9,9), LOF(9,9)
  DATA XN, SE, W, IHN, IHS, IHE, IHW/
  IF(O(1)).EQ.1)WRITE(8,1061)
  IF(M4.EQ.M1)GO TO 302
  IF(O(1)).EQ.1)WRITE(8,1062)
  DO 301 I=1,M2
  DO 301 K=1,M1
  J=2*K
  ALA=(FLOAT(LAF(I,J-1))+LAF(I,J))+(FLA(I,J-1)+FLA(I,J))/60./2.
  ALO=(FLOAT(LOF(I,J-1))+LOF(I,J))+(FLO(I,J-1)+FLO(I,J))/60./2.
  ADD=(CD(I,J-1)-DD(I,J))/120.
  DLA=(FLOAT(LAF(I,J-1))-LAF(I,J))+(FLA(I,J-1)-FLA(I,J))/60.
  DLO=CD(ALA*P)*(FLOAT(LOF(I,J-1))-LOF(I,J))+(FLO(I,J-1)-FLO(I,J))/60.
1061 10.)
  DXX=SQRT(DLA*DLA+DLO*DLO)
  FLA(I,K)=ALA*60.
  LAF(I,K)=FLA(I,K)/60.
  FLA(I,K)=FLA(I,K)-FLOAT(LAF(I,K))*60.
  FLO(I,K)=ALO*60.
  LOF(I,K)=FLO(I,K)/60.
  FLO(I,K)=FLO(I,K)-FLOAT(LOF(I,K))*60.
  IF(O(1)).EQ.1)WRITE(8,1063)I,J,K,ALA,ALO,ADD,DLO,DLA,LAF(I,K),FLA(I
1061 1,K),LOF(I,K),FLO(I,K)
  DD(I,J)=DD(I,J)+DD(I,J-1)+DXX)/2.
301 DD(I,K)=DD(I,K)+DD(I,J-1)+DXX)/2.
302 CONTINUE
  I=1,M2
  DO 151 I=1,M2
  DO 151 J=1,M1
  WIND(2,J,I)=WIND(2,J,I)+FLOAT(LOF(I,J))+FLO(I,J)/60.-10.
55 IF(LAF(I,J))52,55,53
53 IF(FLA(I,J))52,53,53
  GO TO 54
52 DE(I,J)=S
  LAF(I,J)=-LAF(I,J)
  FLA(I,J)=-FLA(I,J)
54 IF(LOF(I,J))56,57,58
57 IF(FLO(I,J))56,58,58
58 IF(FLA(I,J))56,58,58
  GO TO 151

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56 HE(I,J)=E
   LDF(I,J)=-LCF(I,J)
   FLO(I,J)=-FLO(I,J)
2   IF(LDF(I,J).LT.360)GO TO 151
   LDF(I,J)=LDF(I,J)-360
   GO TO 2
151 CONTINUE
1062 FORMAT(2X,'SEARCH',5X,'TRACK',5X,'START',6X,'ALA',7X,'ALO',7X,'ADD',
17X,'DLA',7X,'DLO',7X,'FLA',7X,'LOF',7X,'FLO')
1063 FORMAT(15,2I10,F13.3,4F10.3,I10,F10.3)
   RETURN
   END
-----
SUBROUTINE RADII
PROGRAMMER: LT J.H. DISCENZA,USCG

THIS SUBROUTINE COMPUTES THE PROPER SERACH RADIUS FOR
EACH DATUM POINT IN EACH SEARCH. IF THERE IS TO BE "NO"
SEARCH AT A PARTICULAR DATUM TIME, SEARCH RADII FOR THAT
TIME ARE SET AT ZERO.

ENTERING ARGUMENTS:

LAD,YLA,LLOD,YLO: LATITUDES AND LONGITUDES OF STARTING
POSITIONS
LAK,ALK,LLOK,OLK: LATITUDE AND LONGITUDE OF LAST KNOWN
POSITION
IX1: DRIFT RATE AS PERCENT OF WIND
IX2: DRIFT DIVERGENCE IN TENS OF DEGREES
X1,X2: COEFFICIENTS OF EQUATION FOR DETERMINING
DISTRESS CRAFT POSITION ERROR.
Y: SEARCH CRAFT POSITION ERROR
KJ: SEARCH NUMBER GENERATED:
INTERMEDIATE ARGUMENTS OF LATITUDE, LAST KNOWN POSITION
COSLAT: COSINE OF LATITUDE, LAST KNOWN POSITION
X: DISTRESS CRAFT POSITION ERROR
C: TOTAL PROBABLE ERROR
SF: SAFETY FACTOR (BASED ON SEARCH NUMBER)
DX: DISTANCE FROM LAST KNOWN POSITION

OUTPUTS:
RADIUS: SEARCH RADIUS (RADIUS=0. INDICATES NO
CALCULATION OF SEARCH AREA DESIRED FOR THAT TIME.)

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SAR07520
SAR07530
SAR07540
SAR07550
SAR07560
SAR07570
SAR07580
SAR07590
SAR07600
SAR07610
SAR07620
SAR07630
SAR07640
SAR07650
SAR07660
SAR07670
SAR07680
SAR07690
SAR07700
SAR07710
SAR07720
SAR07730
SAR07740
SAR07750
SAR07760
SAR07770
SAR07780
SAR07790
SAR07800
SAR07810
SAR07820
SAR07830
SAR07840
SAR07850
SAR07860
SAR07870
SAR07880
SAR07890
SAR07900
SAR07910
SAR07920
SAR07930
SAR07940
SAR07950

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SUBROUTINE RADII
COMMON LAD(9),YLA(9),D(9),LOD(9),YLO(9),H(9),M1,CHECK,0,
1DE(9,9),HE(9,9),T2,T3,A1,TZ(9),MON(9),IX1,IX2,TAP,
2DESC(15),FILA(9,18),FLO(9,18),LAF,LCF,M2,M4,M6,CV1,CV2,CV3,CV4,
3CD1,CD2,P,DD(9,18),RADIUS(9,9),C(9,18),WIND(2,9,9)
INTEGER A1(3,9),T2(3,9),T3(3,9),O(9)
INTEGER LAF(9,9),LCF(9,9),KR(9)
DIMENSION SF(9)
C      ENTER LAST KNOWN POSITION
WRITE(6,3001)
3001 FORMAT(' ENTER LAST KNOWN POSITION. EX: 3522.ON,07653.0W')
3002 READ(5,3002)LAK,ALK,LCK,CLK
C      FORMAT(I2,F4.0,2X,I3,F4.0)
COSLAT=COS((FLOAT(LAK)+ALK/60.)*P)
C
WRITE(6,3003)DESC
3003 FORMAT(' IS ',15A4)
3004 WRITE(6,3004)
3004 FORMAT(' A (1)BOAT, (2)SHIP, OR (3)AIRCRAFT?(ENTER 1,2,OR3)')
3005 READ(5,3005)LL
C      FORMAT(I1)
IF(LL-2)602,603,604
C      SMALL BCATS
602 X1=15.
X2=.15
GO TO 605
C      SHIPS
603 X1=5.
X2=.05
GO TO 605
C      AIRCRAFT
604 X1=10.
X2=.1
C
605 WRITE(6,3006)
3006 FORMAT(' ENTER SEARCH UNIT FIX ERROR, Y. EX: 5.0')
3007 READ(5,3007)Y
C      FORMAT(F20.0)
YSQ=Y*Y
C
WRITE(6,3008)
3008 FORMAT(' INDICATED DISTRESS CRAFT POSITION ERROR,X:')
3009 WRITE(6,3009)X1,X2
3009 FORMAT(' X=',F6.2,'(1) +',F6.2,'(2) TIMES DIST. FROM LAST KNOWN POSI
1SITION.')
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SAR07960
SAR07970
SAR07980
SAR07990
SAR08000
SAR08010
SAR08020
SAR08030
SAR08040
SAR08050
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SAR08070
SAR08080
SAR08090
102 SAR08100
SAR08110
103 SAR08120
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SAR08140
SAR08150
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SAR08180
SAR08190
104 SAR08200
SAR08210
SAR08220
SAR08230
105 SAR08240
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106 SAR08280
SAR08290
SAR08300
107 SAR08310
SAR08320
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SAR08350
SAR08360
108 SAR08370
SAR08380
109 SAR08390
SAR08400
SAR08410
SAR08420
SAR08430

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610 WRITE(6,3010)
3010 FORMAT(' ANY CORRECTIONS? (TYPE 0,1,2, OR 12)')
3011 READ(5,3011)I1,L2
      FORMAT(2I1)
      IF(L1-1)606,607,608
607 WRITE(6,3012)I1
3012 FORMAT(' ENTER PARAMETER('',I1,''):')
      READ(5,3007)X1
      IF(L2-2)606,608,609
608 WRITE(6,3012)I2
      READ(5,3007)X2
      GO TO 606
609 WRITE(6,3013)I2
3013 FORMAT(' INCORRECT. RESPONSE:',I1,' -NO PARAMETER GREATER THAN 2.')
      GO TO 610
C
606 DO 611 J=1,M1
      DXN=FLOAT(LAD(J)-LAK)*60.+YLA(J)-ALK
      DXW=(FLOAT(LAD(J)-LOK)*60.+YLO(J)-OLK)/COSLAT
      DX=SQRT(DXN*DXN+DXW*DXW)
      X=X1+X2*DX
      XSQ=X*X
      DO 611 I=1,M2
        C(I,J)=SQRT(XSQ+YSQ+DD(I,J)*DD(I,J))
611 WRITE(6,3014)
3014 FORMAT(' IS EACH DATUM TIME A DIFFERENT SEARCH (1,2,3,ETC.)?')
3017 READ(5,3017)RESP
      FORMAT(1A1)
      DATA WRONG/1HN/
      IF(RESPEQ.WRONG)GO TO 612
      GO TO 613
612 WRITE(6,3015)
3015 FORMAT(' ENTER SEARCH NUMBER CORRESPONDING TO DATUM TIME:')
      DO 614 I=1,M2
        WRITE(6,3016)(T2(J,I),J=1,3)
3016 FORMAT(3I2,' SEARCH:')
614 READ(5,3005)KR(I)
      GO TO 615
613 DO 616 I=1,M2
      KR(I)=I
616 KR(I)=I
615 DO 617 J=1,M2
      IF(KR(J).EQ.0)GO TO 618
      IF(KR(J).GE.5)GO TO 625
      KK=KR(J)
      GO TO(621,622,623,624),KK
C
C
C
131 SAR08850
132 SAR08860
133 SAR08870
134 SAR08880
135 SAR08890
136 SAR08900
137 SAR08910
138 SAR08920
139 SAR08930
140 SAR08940
141 SAR08950
142 SAR08960
143 SAR08970
144 SAR08980
145 SAR08990
146 SAR09000
147 SAR09010
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621 SF(J)=1.1
622 GO TO 617
623 SF(J)=1.6
624 GO TO 617
625 SF(J)=2.17
626 GO TO 617
627 SF(J)=2.33
628 GO TO 617
629 SF(J)=2.5
630 GO TO 617
631 SF(J)=0.
632 CONTINUE
633 DO 619 I=1,M2
634 DO 619 J=1,M1
635 RADIIUS(I,J)=SF(I)*C(I,J)
636 RETURN
637 END

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SAR08920
SAR08930
SAR08940
SAR08950
SAR08960
SAR08970
SAR08980
SAR08990
SAR09000
SAR09010
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SAR09030
SAR09040
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SAR09060
SAR09070
SAR09080

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SUBROUTINE FNIQ(LAT,TLA,LOT,TLO,SI,SJ,FM,K)
IF(K.GT.0)GO TO 1
TLAT=(FLOAT(LAT)+TLA/60.)/57.29578
TLOT=(FLOAT(LOT)+TLO/60.+10.)/57.29578
Q=SIN(TLAT)
A=31.205*SQRT((1-Q)/(1+Q))
S=SIN(TLOT)
CC=CCOS(TLOT)
SI=32.+A*CC
SJ=32.-A*S
GO TO 3
1 XX=SI-32.
YY=32.-SJ
IF(ABS(XX).GE.0.00005)GO TO 4
XLON=80.
IF(YY.LT.0.)XLON=-100.
GO TO 5
4 TN=YY/XX
XLON=ATAN(TN)*57.29578-10.
IF(XX.LT.0.)XLON=XLON+180.
FSQ=XX*XX+YY*YY
RSE=973.752
Q=(RSE-RSQ)/(RSE+RSQ)
XLAT=ARCSIN(Q)*57.29578
LAT=XLAT
LOT=XLON
TLA=60.*(XLAT-FLOAT(LAT))

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SAR09090
SAR09100
SAR09110
SAR09120
SAR09130
SAR09140
SAR09150
SAR09160
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SAR09310
SAR09320
SAR09330
SAR09340
SAR09350

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3 TLO=6C.*(XLCN-FLOAT(LOT))
FM=388.8556/(1.+Q)
RETURN
END
PEAL FUNCTION SWIDTH(SL,VIS,ALT,WIND,CC)
X=ALOG(SL)
Y=ALOG(VIS)
IF(ALT.GE.200.)GO TO 1
Z=ALT
GO TO 2
1 Z=ALT/1000.
2 XX=-3.34377+1.25887*X+2.55442*Y+0.01023*Z
XW=WIND/10.
F1=.886+XW*(.298-.116*XW)
F2=1.131-CC*(-.472+.152*CC)
SWIDTH=XX*F1*F2
RETURN
END
INTEGER FUNCTION JULIAN(XMO,N)
DIMENSION C(12),J(12)
DATA C(1),C(2),C(3),C(4),C(5),C(6),C(7),C(8),C(9),C(10),C(11),C(12)/
3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,3HJUN,3HJUL,3HAUG,3HSEP,3HOCT,
23HNOV,3HDEC/
DATA J(1),J(2),J(3),J(4),J(5),J(6),J(7),J(8),J(9),J(10),J(11),J(12)/
1 0,31,59,90,120,151,181,212,243,273,304,334/
DO 1 I=1,12
IF(C(I).EQ.XMO)GO TO 2
CONTINUE
JULIAN=0
GO TO 3
2 JULIAN=J(I)+N
3 CONTINUE
RETURN
END

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SAR09360
 SAR09370
 SAR09380
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 SAR09400
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 SAR09420
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 SAR09680
 SAR09690


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14 6 GO TC 6
    WRITE(6,22) I, RADIUS
6 CONTINUE
DO 40 I=1,400
40 XSP(I)=FLOAT(I)/100.
    W=0.0
    WRITE(6,100)
    SF(1)=1.1
    SF(2)=1.6
    SF(3)=2.0
    SF(4)=2.3
    SF(5)=2.5
DO 99 II=1,2
    SET SWEEP WIDTH
    W=W+0.05
    WPER=W/1.18
    IF(II.EQ.1) WRITE(6,106)
    WRITE(6,103) WPER
DO 99 IQ=1,2
    IF(IQ.EQ.2) WRITE(6,105)
DO 42 I=1,400
    X(I)=XX(I)
    P(I)=PRO(I)
DO 99 II=1,5
DO 41 I=1,400
41 ZSP(I)=P(I)
    YSP(I)=X(I)
    MN=2
    IF(II.EQ.1) MN=1
    IF(II.EQ.5) MN=3
    USING SAFETY FACTOR FIND LENGTH, EFFORT
    SIZE=SF(II)*1.18
    XL=4.*SIZE*SIZE/(FLOAT(IQ)*W)
    XLER=XL/1.18
    EFFORT=WPER*XLER
    WRITE(6,104) XLER, EFFORT
C
C FIND PROBABILITY OF SUCCESS FOR THIS SEARCH AREA
    PSTAN=POD(W*XL/(4.*SIZE*SIZE))
    D=0.01000
    J=SIZE*100.
    IF(J.GT.400) J=400
    FOLD=P(J)*PCD(W*XL/(4.*SIZE*SIZE))
    SIZE=SIZE+.01
    PSTAN=POD
    J=SIZE*100.
    IF(J.GT.400) J=400

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SOL00330
SOL00350

SOL00410
SOL00360
SOL00370
SOL00380
SOL00390
SOL00400

SOL00420

SOL00430

SOL00460

SOL00480
SOL00490

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C      FIND SIZE WHICH MAXIMIZES PROBABILITY OF SUCCESS, PMAX
C      PR= P(J)*PCD(W*XL/(4.*SIZE*SIZE))
11      IF(PR-POLD)11,2,3
C      D=-.01000
C      SIZE=SIZE-.01
C      GO TO 4
C      POLD=PR
C      SIZE=SIZE+D
C      J=SIZE*100.
C      IF(J.GT.400)J=400
15      PR= P(J)*PCD(W*XL/(4.*SIZE*SIZE))
C      IF(PR-POLD)15,2,16
C      PMAX=POLD
C      GO TO 2
C      POLD=PR
C      SIZE=SIZE+D
C      GO TO 7
C      I=SIZE*100.
C      B=PCD(W*XL/(4.*SIZE*SIZE))
C      K=SF(II)*118.
C      SI=ELQAT(IQ)*W/1.18
C      SAZE=SIZE/1.18
C      S=4.*SAZE*SAZE/XL
C      WRITE(6,101)II,SAZE,S,P(I),B,PMAX,SF(II),SI,P(K),DSTAN,PSTAN
C      IF(II.EQ.5)GO TO 99
C      FIND BAYES MULTIPLIER FOR PROBABILITIES INSIDE SEARCH AREA
C      RAYIN=(1.-B)/(1.-PMAX)
C      FIND BAYES MULTIPLIER FOR PROBABILITIES OUTSIDE SEARCH AREA
C      RAYOUT=1./(1.-PMAX)
C      USING BAYES' LAW, REEVALUATE DENSITY FUNCTION AND
C      PROBABILITY DISTRIBUTION
C      DO 10 J=1,400
C      IF(J-I)30,31,32
30      P(J)=P(J)*BAYIN
C      X(J)=X(J)*BAYIN
C      GO TO 10
C      PRACK=P(J)
31      P(J)=P(J)*BAYIN
C      X(J)=X(J)*BAYIN
C      GO TO 10
C      F(J)=P(I)+BAYOUT*(P(J)-PRACK)
32      F(J)=X(J)*BAYOUT
C      CONTINUE
C      10 CONTINUE
C      99

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SOL00510
 SOL00520
 SOL00560
 SOL00540
 SOL00550
 SOL00570

SOL00590
 SOL00600
 SOL00610
 SOL00620
 SOL00630
 SOL00640

SOL00710

SOL00780


```

AND PI=3.14159
H(X)=2./SQRT(PI)*J(EXP(-BETA**2)D(BETA)
WHERE "J(*)D(R)" INDICATES THE DEFINITE INTEGRAL OF "*"
THE AREA OF EITHER FUNCTION CAN BE OBTAINED IN FIVE DIFFERENT
FORMS
OF AREAL SEGMENTS, NAMELY:
1. CENTRAL
2. SEMI-CENTRAL
3. TWO-TAIL
4. SINGLE-TAIL
5. CUMULATIVE FROM MINUS INFINITY.
C. USAGE:
1. CALLING STATEMENT:
CALL NPOA(XARG, ITYPE, ORD, AREA, ERR)
2. ARGUMENTS:
XARG - ARGUMENT ON THE ABSCISSA. (REAL*8)
FOR P(X) THE ARGUMENT MUST LIE:
0 .LE. ABS(X) .LE. 13.258609
FOR H(X) THE ARGUMENT MUST LIE:
0 .LE. ABS(X) .LE. 9.382323
ITYPE - SIGNED INTEGER VARIABLE WHICH SPECIFIES FUNCTION
TYPE AND FORM OF THE ORDINATE AND/OR AREA.
ITYPE FORM
P(X) H(X)
+1 -1 CENTRAL AREA FROM -X TO ABS(X)
+2 -2 SEMICENTRAL AREA FROM ZERO TO ABS(X)
+3 -3 TWO-TAIL AREA BEYOND -ABS(X) AND +ABS(X)
+4 -4 SINGLE-TAIL AREA BEYOND ABS(X)
+5 -5 AREA FROM MINUS INFINITY TO ABS(X)
+6 -6 ORDINATE VALUE ONLY
ORD - ORDINATE ANSWER (REAL*8)
AREA - AREA ANSWER (REAL*8)
ERR - ERROR INDICATOR WHICH DENOTES RETURN FROM THE
SUBROUTINE. (REAL)
SUCCESSFUL RETURN, ERR = 0.0
UNSUCCESSFUL RETURN, ERR = +1.0
ERR = -1.0
3. ERROR RETURNS:
IF THE ARGUMENT EXCEEDS THE LIMIT AS DEFINED IN C2, THE FOLLOWING
VALUES WILL RESULT:
ITYPE AREAL SEGMENT
-----
1 CENTRAL AREA
2 SEMICENTRAL AREA
ORD AREA
---
0 1.0
0 0.5

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SOL01270
SOL01280
SOL01290
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SOL01690
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SOL01740

14
17
16
18
ORD=0.3535533905*ORD
ERR=0.0
GO TO 19
ERR=1.0
RETURN
END

SOL02190
SOL02200
SOL02210
SOL02220
SOL02230
SOL02240

References

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DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

Naval Postgraduate School
Monterey, California 93940

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

3. REPORT TITLE

Computerized Survivor Search Planning

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Master's Thesis (June 1969)

5. AUTHOR(S) (First name, middle initial, last name)

Joseph H. Discenza

6. REPORT DATE

7a. TOTAL NO. OF PAGES

118

7b. NO. OF REFS

6

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

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Monterey, California 93940

13. ABSTRACT

A computer program is presented which solves the search planning problem for survivors at sea. The program is designed to utilize weather data as compiled by the United States Navy at its Fleet Numerical Weather Central, Monterey, California.

An investigation is also made into the search criteria used by the United States Coast Guard in its planning procedures. Guidelines are given for the use of the square search and the Sector search.

14

KEY WORDS

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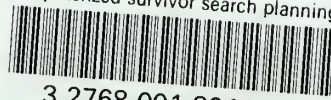
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